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SOME EFFECTS OF TEMPERATURE ON THE FROST RESISTANCE OF APPLE FLOWERS

By G. C. HEAD
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THE frost resistance or hardiness of agricultural and horticultural plants has formed the subject of several recent reviews (Levitt, 1941 ; Scarth, 1944 ; Chandler, 1954 ; Levitt, 1956). Most attention has, however, been directed towards the effects of extreme winter temperatures. Under these conditions plants are usually dormant and often endure temperatures below 0° F. for periods of weeks, rather than minutes or hours. These " hardy " plants generally show improved hardiness after exposure to non-damaging low temperatures (Levitt, 1941). In rapidly growing tissues the degree of frost resistance is low, and often no increase is observed after exposure to low temperature. The present experiments were designed to investigate the ability of apple flowers to increase their frost resistance and to study the accompanying physiological changes.

Material and methods.

Cordon trees of the apple variety Ellison's Orange, grown in 10-inch clay pots, were used in the experiments (Fig. 1). In the first two of these the rootstock was M.IX and in the remainder M.VII. Eight trees were used in each experiment, half of them receiving what will be called the " warm " temperature treatment, while the others had the " cool " treatment.

To fit in with other experiments, the trees were forced so that they flowered in March or April, that is one or two months before their natural blossom season. Those trees, in each experiment, which were eventually to receive the cool treatment were forced slightly ahead of those for the warm treatment ; when the cool treatment was applied it slowed up the rate of development and eventually the trees in the warm treatment caught them up. The period of treatment varied in different experiments from seven to twenty days. On the day when the trees of each treatment were judged to be at the same stage of flower development, all were moved to the freezing chamber and subjected to controlled low temperature conditions.

In the first experiment the temperature treatments were given by placing the trees in either a heated or an unheated greenhouse. In the remainder of the experiments the cool treatment was given in a fruit store equipped with artificial illumination consisting of 80-watt fluorescent tubes arranged as shown in Fig. 1, the banks of tubes being approximately two feet apart. The night minimum temperature was controlled by cooling machinery operated by a thermostat, this and the lights being operated by time switches so that, as the lights switched off after a 16-hour day, the cooler was switched on to give a controlled low temperature during the night. When the lights switched on again in the morning the cooler was automatically switched off.

During the day the temperature gradually rose because of the heat generated by the fluorescent lights. The " warm " trees were grown in a warm greenhouse, the natural daylight being extended with artificial illumination to give a 16-hour day. The temperatures employed varied slightly in each experiment, the " cool " trees usually being about 10° C. below the warm ones. The cool treatment consisted of night temperatures of 34°–36° F. (1°–2° C.) rising to 50°–60° F. (10°–15° C.) during the day, as against 50°–60° F. (10°–15° C.) and 65°–75° F. (18°–24° C.) respectively for the warm treatment.

On the day before the trees were to be frozen, samples consisting of four flowers at each stage of development (shown in Table I) were removed from each tree for analyses of water and sugar contents. The samples were weighed immediately after picking and then stored at –20° C. for two to six months, until it was convenient to analyse them. In each experiment great care was taken to ensure that all the samples collected consisted of flowers of exactly the same stage of development. If pink buds were required, then buds with approximately the same amount of petal showing between the sepals were selected ; if open flowers were required, those just commencing to dehisce their anthers were chosen.

On removal from storage the samples were immediately dried with phosphorus pentoxide under vacuum and weighed again. Extraction, separation and determination of the total sugars was carried out by a method, recommended by Drs. Bradfield and Flood, which involves grinding the dry material in a roller mill and percolation at room temperature, first with dry acetone and then with 80 per cent. acetone. Separation of the sugars from the polyphenols was achieved by paper chromatography with 2 per cent. acetic acid as the solvent. The strip of paper carrying the sugars was pulped in a known volume of water and determination of the sugars was carried out by a colorimetric modification of the Hagedorn and Jensen method. Fuller details of this method will be published later.

Testing for frost resistance was carried out in a special refrigerated chamber, recently described by Slater (1957), the temperature of the room being lowered at a standard rate of 1·2° C. per hour. The trees were exposed to a minimum temperature of –3·0° C., for 40 minutes in Exp. 2 and for 45 minutes in the others. At the end of the period of freezing, the room temperature was raised quickly. The ice present in the flowers thawed completely in twenty to thirty minutes.

RESULTS.

In general it was found that flowers on trees in the warm treatment developed approximately twice as quickly as those in the cool treatment. Interesting differences between the rates of development of younger and older buds of the trees under cool treatment were also noted : pink buds that were nearly ready to open when the treatment began were little checked, whereas the younger pink buds enlarged only very slowly, if at all. On the trees in the warm greenhouse all ages of bud enlarged at about the same rate.

Difference in temperature also affected the final size of flowers and leaves. The flowers from the cool treatment were much smaller, had narrower petals (Fig. 2) and usually weighed less. The leaves of the trees from the cool treatment always appeared darker green, were smaller and usually the petioles were bent downwards. The difference in leaf colour was less apparent when the leaves were picked and brought into the laboratory, and chemical analysis showed no consistent differences in

TABLE I.

Percentage of flowers or buds frost-damaged after cool or warm pre-freezing treatments.

Experiment No.	Treatment	Stage of development				
		Petals fallen	Open flowers	Late pink bud	Early pink bud	Green cluster
1	Cool				0·5 ***	1·2 **
	Warm				43·6	14·5
2	Cool	76·0	27·0 ***	3·5 ***	1·1 **	
	Warm	94·5	66·4	47·6	60·0	
3	Cool		78·2	22·7 ***	2·2 ***	
	Warm		87·5	77·0	52·1	
4	Cool		24·5 **	13·3 ***	7·4 ***	
	Warm		60·0	57·7	54·7	
5	Cool		16·7 **	2·5 ***	2·2 ***	
	Warm		56·0	55·1	54·6	

** and *** indicate differences significant at the 1 and 0·1 per cent. levels of probability respectively.

nitrogen, phosphorus, calcium or magnesium content. Potassium showed a small, but significant, increase in the trees from the cool treatment.

Table I gives results of the freezing tests, the criterion of frost damage being discoloration of the styles. The figures shown are means of the four trees in each treatment ; at least fifty and generally more than two hundred flowers in each category were recorded in each experiment. The figures show clearly that apple buds and flowers at each stage from green cluster to petal fall can become more frost-resistant as a result of previous low temperature treatment.

Comparison of the damage to flowers of the various stages of development within an experiment shows that, in general, those more advanced were more severely damaged, this being in agreement with orchard experience for this variety. The differences in the amount of damage shown by the different stages were, however, much greater for the trees from the cool than from the warm treatment. Exp. 2 and Exp. 3 are good examples of this, the difference between the treatments being only 10–18 per cent. for the most advanced stages and 50–60 per cent. for the youngest stages.

In all experiments except the first, analyses of sugar and water contents were carried out on the receptacle only, the petals having been removed. In Exp. 1 whole buds were used. The results of these analyses are given in Table II. In all the experiments the differences in water content between the two treatments were small but consistent, the buds from the cool treatment always having a lower water content. Results of the sugar analyses are presented for the last three experiments, the samples analysed from these all being at the same stage of development. In each experiment the cool treatment increased the percentage of total sugars in the dry weight by at least 50 per cent. Similar increases were found in buds older and younger than those mentioned, although the results are not tabulated here. In some experiments separate analyses of reducing sugars were carried out. These showed that the ratio of reducing to non-reducing sugars was higher in the flowers from the warm treatment.

TABLE II.

Water content and sugar content of buds from cool and warm temperature treatments.

Experiment No.	Stage of development	Treatment	Water content, % fresh weight	Total sugars, % dry weight
1	Green cluster	Cool	79·6 *	
		Warm	80·4	
2	Open flower	Cool	74·2 ***	
		Warm	78·8	
3	Pink bud	Cool	78·0 ***	9·4 **
		Warm	81·6	5·9
4	Pink bud	Cool	78·2 ***	11·0 ***
		Warm	80·6	7·0
5	Pink bud	Cool	77·9 ***	11·1 ***
		Warm	80·7	7·0

*, **, and *** indicate differences significant at the 5, 1 and 0·1 per cent. levels of probability respectively.

DISCUSSION.

From the data presented above a mental picture of the flowers which resulted from the cool and warm treatments can be built up. Those from the former, and especially the younger buds, grew more slowly and usually were smaller in final size. They had a lower water content, a higher sugar content, and were always less damaged by exposure to controlled low temperature than were the flowers from the warm treatment.

The frost damage to buds of different stages of development in the two treatments was linked with the rate of bud development at the time of freezing. While it was usual for the younger buds to be less damaged than further developed ones, in the cool treatment this difference was much exaggerated. The flowers on these trees were enlarging more slowly than those from the warm greenhouse and were less damaged. The greatest reduction in damage occurred in the youngest buds which suffered the greatest reduction in their rate of development.

Previous orchard experience with apple flowers indicates that climatic conditions preceding spring frosts do affect frost resistance, but some early experimental work (Field, 1939, 1942) was inconclusive.

Changes in water and sugar contents have frequently been associated with increased frost hardiness of plants after exposure to low temperature (Levitt, 1941). When resistance to winter freezing is being considered, the relationship between increase in solutes and hardiness does not always coincide in time (Siminovitch and Briggs, 1949) and consequently in these cases increase in solute concentration is thought to be only a supplement to other more fundamental changes affecting frost hardiness.

When considering possible mechanisms of frost hardiness, or prevention of freezing, it is important to keep in mind the type of freezing which causes damage to the material under investigation. In plants subject to winter freezing there is considerable resistance to intracellular freezing and damage is thought to be caused by

extracellular ice. Frost hardiness in such cases depends on resistance to desiccation or to distortion of the protoplasm by the extracellular ice (Levitt, 1956).

In apple flowers the first ice to form is in the intercellular spaces of the tissue under the hypodermis of the receptacle (Dorsey, 1940 ; Modlibowska and Rogers, 1955). This type of freezing takes place very readily and in these experiments occurred regularly in all flowers of both treatments ; extracellular freezing did not result in death of the cells and was in no way detrimental to the survival of the flowers. Damage to the styles and ovules is almost certainly due to intracellular ice formation. Accumulation of extracellular ice has never been observed in these regions and it is extremely unlikely that the dehydrating and distorting forces of extracellular ice could be severe enough to cause damage in 45 minutes at $-3 \cdot 0°$ C.

Thus the " frost resistance " of apple flowers referred to in this paper differs from Levitt's (1956) " frost hardiness " in that it is based upon the ability of the plant to prevent intracellular freezing.

The results presented above illustrate some of the possible relationships between frost resistance in apple flowers and certain of their physiological characteristics. It is clear that when frost resistance is induced by temperature treatment, there are related differences in the rate of development and also in the sugar and water contents, but it would be unwise, without further evidence, to infer a direct causal connection. These physiological properties may be related to temperature independently, with no relation to each other or to frost resistance. The rate of development itself is unlikely to affect frost resistance directly but rather through associated biochemical and biophysical effects. Possible relationships between water and sugar contents and resistance to intracellular freezing are obvious, although the effect of such small changes in total sugars, as were demonstrated in these experiments, on the lowering of the freezing point of the cell sap would be small (of the order of $0 \cdot 15°$ C.). Cells, however, rarely freeze as soon as the ambient temperature reaches their freezing point, and there is evidence (Lusena and Cook, 1954) that solute concentration affects supercooling even more than it affects the freezing point.

SUMMARY.

Experiments are described in which potted apple trees, in the process of opening their blossoms, were given two different temperature regimes for a week or more before being subjected to artificial freezing.

The results show that in the variety Ellison's Orange the cool temperature treatment reduced the rate of development of the blossoms, ultimately producing smaller flowers with a lower water and higher sugar content than those from the warm treatment. The flowers from the cool treatment were always less damaged by artificial freezing than those from the warm treatment.

The results are discussed in relation to theories of frost resistance.

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PLATE I.

Fig. 1.

Cordon apple trees growing with artificial illumination in the cool temperature chamber.

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FIG. 2.

Typical flower clusters from warm treatment (*top*) and cool treatment (*bottom*), showing difference in flower size.

THE YIELD OF ONIONS AND RED BEET AS AFFECTED BY WEEDS

By J. K. A. BLEASDALE
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THE use of herbicides for weed control in vegetable crops is now well established. There is, however, a lack of quantitative data on how the use of herbicides should be combined with cultural practices to obtain the highest yields consistent with the economic use of labour.

A reduction in the weed stand brought about by the use of pre-emergence herbicides could be expected to delay the onset of competition between the crop and the weeds, and to reduce the amount of labour needed for subsequent weed control. The stage of growth at which this subsequent weed control is done might affect crop yield. In this paper three experiments on the effects of delaying weed removal in crops of onions and red beet are described. In each experiment there were two weed densities and three dates of weeding.

Experimental procedure.

The experiments were carried out at Wellesbourne, Warwick, on a sandy loam of medium-low fertility. Appropriate fertilizers were applied prior to spring discing and the seedbeds were prepared by harrowing and ring rolling. The experiments were of randomized block design with initially nine treatments (3 weed stands × 3 dates of weeding). In all three experiments contact pre-emergence herbicides were used to reduce the full natural weed stand on some plots in an attempt to obtain three different weed densities. The rates of application and the type of herbicide used make it unlikely that these treatments had any adverse effect on crop growth. For various reasons only two weed densities were obtained in any one experiment and the statistical analysis of the results was suitably modified.

The details of the experimental procedure are summarized in Table I. The herbicide killed almost all weeds that had emerged at the time of application. Subsequent emergence gave a weed stand slightly younger and less dense than that on the unsprayed plots.

In all the experiments the whole area was mechanically cultivated between the rows prior to the first hand weeding, leaving a $3\frac{1}{2}$ in. wide band of undisturbed soil in each crop row. The first weeding was done as early as was practicable. Counts at each treatment weeding date showed that the weed stand did not increase as weeding was delayed. After the weeding treatments had been completed, the whole experimental area was kept as free from weeds as possible in order to ensure that the effects of previous weed control treatments were not masked by subsequent weed growth. This usually meant that the land was cultivated between the rows twice and any weeds remaining in the rows were removed by hand.

TABLE I.

Details of the experiments.

	Onions, 1956	Onions, 1957	Red beet, 1957
Variety	Best of all	Suttons A.I	Detroit (globe)
Row spacing	16 in.	16 in.	16 in.
Plants per yd. of row	20	35	16
Sowing date	20th March	4th April	4th June
Herbicide	Pentachlorophenol*	Cresylic acids†	Cresylic acids†
Date of application of herbicide	15th April	24th April	11th June
Emergence date	16th April	25th April	14th June
Length of row harvested per plot	60 ft.	50 ft.	50 ft.
Replication	6	6	4
Weeding dates	16th May, 25th May, 13th June	22nd May, 29th May, 13th June	28th June, 5th July, 12th July
Main weed species	*Fumaria officinalis* agg.	*F. officinalis* agg., *Chenopodium album* agg.	*F. officinalis* agg., *Chenopodium album* agg., *Poa annua* L.
Date of harvest	October	October	30th August
No. of plots per block with full weed stand	3	6	3

* A proprietary formulation in emulsifiable non-persistent oil, applied at the rate of 1 lb. pentachlorophenol per acre.

† A proprietary formulation, applied at the recommended rate.

RESULTS.

The amount of labour used for hand weeding.

The time taken to hand-pull the weeds within the rows in each plot was recorded at each weeding date. The data are presented in Table II where the times are given as minutes per 50 ft. of row. The same worker weeded plots in the same block on each date. The workers were experienced and accustomed to being timed, and it is therefore unlikely that the rate of working was affected by the presence of a recorder.

TABLE II.

Mean time, in minutes per 50 feet of row, taken for the first hand-weeding of the rows on three dates with two weed densities.

Onions, 1956			Onions, 1957			Red beet, 1957		
Weeding date	No. of weeds per ft. of row		Weeding date	No. of weeds per ft. of row		Weeding date	No. of weeds per ft. of row	
	6·1	3·3		1·8	1·4		5·0	3·3
16th May	5·4	2·9	22nd May	1·4	0·95	28th June	4·1	2·8
25th May	5·5	2·8	29th May	1·1	0·70	5th July	2·5	1·9
	±0·48*			±0·27			±0·39	
13th June	8·8	4·5	13th June	2·4	1·4	12th July	3·1	2·3
	±0·39†	±0·53‡		±0·32	±0·22		±0·46	±0·32

*, †, ‡: standard errors of the differences between two means; degrees of freedom, 43 for onions and 24 for red beet; * horizontal comparison; † and ‡, within column comparisons. This applies to all Tables.

Less time was always taken in hand weeding where the weed stand had been reduced previously by the application of a herbicide. These reductions were not significant ($P < 0.05$) at all dates of weeding, but combining all the data presented, a 38 per cent. reduction in the weed stand resulted in a 42 per cent. saving in the amount of labour needed for hand weeding.

It usually took longer to remove the weeds on the first weeding date than on the second (see Table II) but this difference was significant only in the experiment on red beet when the first weeding date was particularly early. In the 1957 onion experiment the plots weeded on the first two dates were weeded again on the third. The total times spent on hand weeding are shown in Table III. Although the weed stand did not increase as the date of weeding was delayed, the time taken to weed the plots was greatest on the last occasion (see Table II). The data presented in Table III suggest that this may have been caused by incomplete weed removal at early dates when the weeds were small.

TABLE III.

Mean total times, in minutes per 50 feet of row, taken to hand-weed onion (1957) rows at two weed densities. The plots weeded on the first two dates were weeded again when the last third of the plots was weeded.

First weeding date	Second weeding date	No. of weeds per ft. of row	
		1·8	1·4
22nd May	13th June	2·7	2·0
25th May	13th June	2·3	1·6
		±0·29*	
13th June	—	2·4 ±0·34†	1·4 ±0·24‡

Standard errors as in Table II.

Crop yields.

Table IV summarizes the marketable yields for the three experiments. On every occasion there was a significantly higher yield of red beet where there were fewer weeds. In the onion experiments the differences between crop yield with high and low weed stands were not always significant but there were always higher yields when the weeds were fewer. If the data for the two years are combined the effect of weed stand on the yield of onions was highly significant ($P < 0.01$).

The effects of date of weeding were greatest with the high weed density in the 1956 onion experiment ; the effect on yield at the low weed density in 1956, and at both densities in 1957, was not so marked but the trends were similar in that early weeding always gave the highest yield. Date of weeding did not affect the yield of red beet at the low weed density but at the high weed density the trend was similar to that with onions.

The high yield of marketable onions obtained in 1957 as compared with 1956 is attributable to the higher crop density and the better growing conditions in 1957 (Rubio *et al.*, 1957, 1958). Further, the high crop density in 1957 might have accentuated the adverse effects of relatively low weed densities.

TABLE IV.

Mean marketable yields in tons per acre for three dates of first weeding and two weed densities.

Onions, 1956			Onions, 1957			Red beet, 1957		
Weeding date	No. of weeds per ft. of row		Weeding date	No. of weeds per ft. of row		Weeding date	No. of weeds per ft. of row	
	6·1	3·3		1·8	1·4		5·0	3·3
16th May	7·8	8·5	22nd May	15·4	17·4	28th June	9·6	11·8
25th May	6·4	6·6	29th May	15·4	16·7	5th July	8·4	11·0
	±0·82*			±1·07			±0·87	
13th June	3·7 ±0·67†	5·5 ±0·94‡	13th June	13·4 ±1·23	15·1 ±0·87	12th July	7·8 ±1·02	12·0 ±0·72

Standard errors as in Table II.

In both years there was no significant difference between the final yield of onions at the two weed densities when the weeding was done early. The trend of the results suggests, however, that the observed differences may have been real and this view is strengthened by the result obtained with red beet.

Crop quality.

Onions. These were lifted during September and allowed to ripen in the field for about three weeks before grading and weighing. The grades used (Ministry of Agriculture, 1954) were as follows :

Selected (S) : ripe bulbs $> 2\frac{1}{2}$ in. diameter.

Medium (M) : ripe bulbs, $2\frac{1}{2}$ in. to $1\frac{1}{2}$ in. diameter.

Picklers (P) : ripe bulbs $< 1\frac{1}{2}$ in. diameter.

Unripe (U) : bulbs of all sizes that were thick-necked and had not ripened.

The weight of onions in each grade was recorded for each plot. The weight of unripe bulbs included the green tops, hence on a weight basis there was a disproportionate amount of the crop in this grade. In 1956 the summer at Wellesbourne was abnormally wet and cold and this may be the reason that more of the crop than normal was graded as unripe and therefore unmarketable. These data are presented diagrammatically in Fig. I.

In both years there was a higher weight of onions in the medium grade than in any other, but in 1957 the high plant density produced a much higher proportion of "picklers" than there was in 1956. Delaying hand weeding decreased the yield of selected onions in both years with the high weed stand, and in 1956 with the low weed stand. In 1957, however, delaying the weeding affected the weight of onions in the pickling grade most. The proportion of the crop falling in the unripe grade in 1956 appears to have been increased by delaying the weeding and by the high, as compared with the low, weed stand.

Red beet. Figures for marketable yield have already been presented in Table IV. Roots less than $1\frac{1}{2}$ in. diameter were classed as unmarketable and the weight per plot recorded. So few roots (about four) on each plot exceeded the

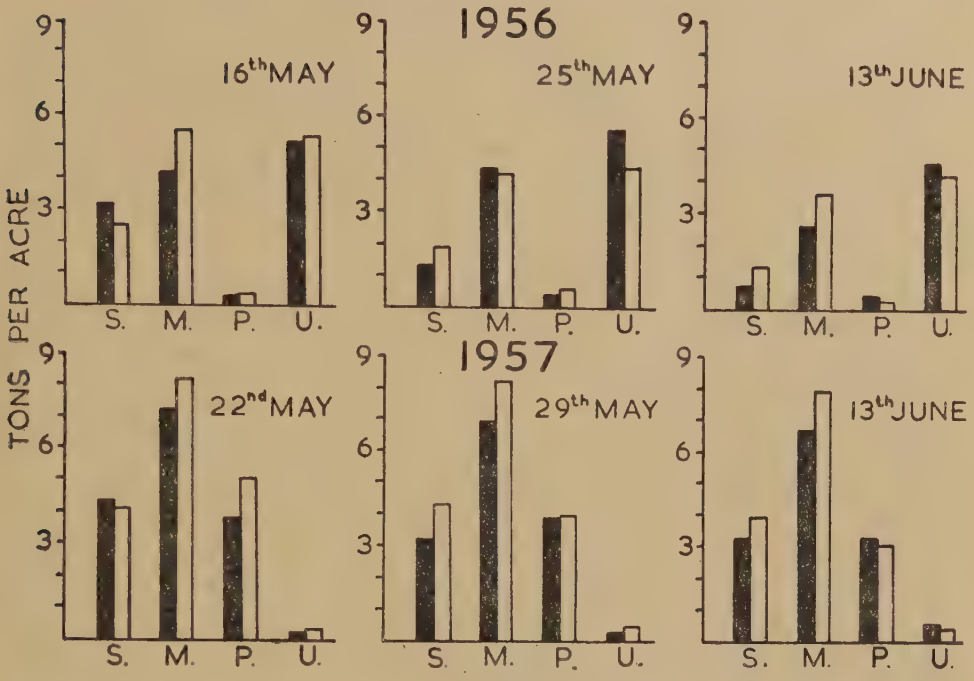

Fig. 1.

Effect of date of first weeding on mean total weight of onions in each grade at harvest—two years' results. S, selected ; M, medium ; P, picklers ; U, unripe. *Black*, yields with full natural weed stand ; *white*, yields with reduced weed stand.

recommended (Ministry of Agriculture, 1951) maximum diameter of 3½ in. that their weight has been included with that of the marketable beet. The weights of unmarketable roots are given in Table V.

Table V.

Mean yields of unmarketable roots (red beet, 1957) in tons per acre for three dates of first weeding and two weed densities.

Weeding date	No. of weeds per ft. of row	
	5·0	3·3
28th June	3·6	3·4
5th July	2·9	3·0
	±0·53*	
12th July	2·1	3·1
	±0·61†	±0·43‡

Standard errors as in Table II.

Delaying weeding did not lead to any significant differences in the weight of unmarketable roots at the low weed density. At the high weed density, however, the weight of unmarketable roots decreased as weeding was delayed.

DISCUSSION AND CONCLUSIONS.

It has been shown that reducing the weed stand prior to hand weeding lessened the amount of hand labour required to remove the weeds remaining within the row after mechanical inter-row cultivation. Bleasdale and Roberts (1957) showed that the time taken to remove the weeds by hand was proportional to the number of weeds. They further demonstrated that, as weeds grew, the time taken to remove them increased. The present data confirm these previous results but there were indications that, when both the crop and the weeds were very small, weeding took longer than it did at a slightly later stage of growth.

In the experiment on red beet a reduction in the amount of weed present prior to the first weeding date gave a significant increase in the yield of marketable roots. In the two onion experiments the lower weed stand gave the higher yield in each year, but the differences were not significant. Thus there is evidence that weeds can affect final crop yield even if they are present only for a short period early in the growth of the crop. Shadbolt and Holm (1952) have reported similar results from experiments with carrots.

In 1957 the yield of onions was affected by delaying the weeding, despite the low weed densities. This may have been partly because of the high crop density. Delaying the weeding did not affect the yield of red beet at the lower weed density and this suggests that there may be a difference in the susceptibility of the two crops to weed competition, onions being the more sensitive.

The results indicate that weeds should be removed at a very early stage if maximum yields of onions and red beet are to be obtained. This means that if a post-emergence herbicide is to be of most value it must be possible to apply it safely to the seedling crop. If this is not possible or if hand weeding is to be employed, then the use of pre-emergence herbicide treatments will probably increase crop yields. The effects of early weed competition on crop quality were relatively small with the weed stands encountered in the experiments. Crop density, weather conditions and variety were major factors affecting the quality of onions.

The pre-emergence herbicides employed reduced the final weed stand by 38 per cent. and the amount of labour needed to hand-weed the rows by 42 per cent. These figures agree closely with the direct proportionality expected (Bleasdale and Roberts, 1957). The reduction in weed stand resulted in a considerable saving in labour and also increased crop yields ; it thus appears that, in these experiments, the use of pre-emergence herbicides was justified economically.

SUMMARY.

1. The results are presented for three factorial experiments which measured the effects of two weed densities and of three dates of weeding on crops of onions (" Best of All " in 1956 and "Sutton's A1 " in 1957) and Detroit (globe) red beet.

2. Reducing the weed density by pre-emergence herbicide treatment increased the crop yields and reduced the amount of labour needed to hand-weed the rows.

3. Very early weeding produced the highest yields ; the longer it was delayed, the smaller was the marketable yield.

4. Crop quality was not greatly affected by weed competition at the early stages of growth.

5. It is concluded that pre-emergence weed control sprays could be profitably used on crops that are to be hand-weeded later or on crops where post-emergence herbicides can be applied only at a fairly late stage of growth.

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A COCOA SHADE AND MANURIAL EXPERIMENT AT THE WEST AFRICAN COCOA RESEARCH INSTITUTE, GHANA

I. FIRST YEAR

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SINCE Ghana is the world's largest producer of cocoa, it may appear strange that earlier research has not established the simpler principles of the manuring of this major crop. Some explanation is therefore called for but, before this is given, the scope for the use of fertilizers should be stressed. There are four million surveyed acres of peasant cocoa in Ghana and these produce a third of the world's total crop. Advances in crop protection have made it possible to reap the benefits of response to fertilizers and progress in plant breeding has resulted in plants which establish easily, come into very early bearing and are capable of heavy yields. Expansion of new planting to virgin soils is limited and replanting is becoming a necessity. It is at least an opportune time for the introduction of the use of mineral fertilizers.

The bulk of the pioneer work on fertilizers for cacao has been done on the western side of the Atlantic and Hardy at the Imperial College of Tropical Agriculture in Trinidad has been particularly associated with this work. Responses to phosphate and potash were obtained in Trinidad in the 1930's. However, in the 1945-51 I.C.T.A. Report, Havord (7) pointed out that the cocoa in these experiments was extremely heterogeneous and only very large increases in yield could be regarded as statistically significant. Consequently, in the post-war years, a new series of field experiments was initiated and the Shade, Spacing and Fertilizer Experiment described by Hardy (6) which began in 1949 is of particular interest.

Until comparatively recently the only mature cocoa available for fertilizer experiments in Ghana has been on peasant-owned farms where the accurate measurement of response to fertilizers is beyond available experimental techniques for several cogent reasons, some of which have been recently reviewed by Hoblyn (8). These are:

(1) The cocoa trees are only a relatively small part of the total vegetation. Huge forest trees rising to 150 feet or more above the cocoa, dense growth of intermediates and a profusion of ground vegetation must inevitably compete for any relatively small additions of nutrients in a fertilizer experiment.

(2) Peasants plant at random. Seedlings from rodent excursions are often allowed to grow unchecked. Age, spacing, and shade conditions are therefore all variable beyond hope of correction by any known field experimental technique on a workable scale.

(3) The West African practice of shading cocoa is totally unlike the system normally employed for tree crops requiring overhead shade. The

normal system at least aims at regular spacing of tall trees which will form a light cover above the economic crop and are kept under some degree of control. The shade over West African cocoa is the original forest, thinned of intermediates and undergrowth sufficiently to permit the growth of cocoa. The density of the shade varies both with the number of trees per acre and with the widely varying habit of the individual trees. The growth of the cocoa is, in general, poor and variable.

(4) Insect damage by capsids has been a limiting factor in field experiments. New growth is immediately liable to severe damage, followed by die-back and possibly secondary invasion by *Calonectria* fungus which causes a progressive canker of the branches.

(5) Swollen shoot virus diseases are a constant threat and may cause death or severe debilitation of trees, but frequent and regular inspection of experimental areas has been effective in limiting this variable factor for some years past.

(6) Variations in soil fertility due to such factors as slope and the resultant catena, fallen forest giants, termitaria, etc. are of themselves sufficient difficulties for a normal replicated field experiment without the complications enumerated above.

Until comparatively recently heavy shade was considered essential for the satisfactory culture of the Amelonado cocoa, which is the predominant type in Ghana. Shade is a loose term covering a complex of many factors. The beneficial effects were supposed to be largely the result of reduced light intensity, stabilization of humidity conditions in the forest climate and the moisture in the soil, stabilization of the nutrient cycle ranging from the subsoil to the tops of the forest giants and the protection of soil from insolation and erosion.

Though the components of the shade complex have been very inadequately studied one must accept the fact that the culture of an economic crop must involve interference with such complexes if an economic yield is to be obtained. It is at least possible that replacement of the forest by cocoa, or by cocoa and planted shade, can be carried out without disastrous consequences.

Some of the postulated benefits accruing to cocoa from the forest shade complex are mainly theoretical and it is possible to advance theories, backed by some evidence, that the shade may also have some detrimental effects. For instance, mature cocoa may require higher light intensities than are available under the forest canopy. The forest may also compete strongly for available nutrients and moisture. In fact peasants in the drier areas of Ghana have found that cocoa grows more successfully with reduced shade. Without doubt many forest trees are hosts for cocoa swollen shoot virus and for capsids. High humidity also appears to encourage black-pod diseases of cocoa.

The necessity for heavy shade over Amelonado as well as for more recently introduced Amazon types was challenged by Adams and McKelvie (1). The removal of shade was invariably followed by heavy capsid attack and all field experimental work was severely hampered until capsid control techniques were evolved. Fortunately, progress during the past two years has been rapid and from 1956 it was possible to introduce effective routine spraying over the whole of the experimental

area of W.A.C.R.I. The improvement in the general condition of all the cocoa has been spectacular and one factor limiting investigation of the shade/nutrient complex has thus been removed. Progress with the control of swollen shoot and black-pod diseases in the experimental area has also been sufficient for pest and disease losses, at least for the time being, to be virtually eliminated as a serious source of error in field experiments.

Benstead (2) realized that clear felling and regularly spaced shade would be requisites for accurate field experimental work of the future. Consequently, an area of land clear-felled in 1947 for an establishment experiment became available for further use in 1956. All the variables enumerated above except the last one have thus been eliminated in an area of cocoa which now affords an opportunity for accurate measurements of the effects of shade removal and fertilizer application.

Although this experiment is of the "black and white contrast" type, it marks a definite advance in the progress of shade/fertilizer experimental work in Ghana.

Materials and methods.

Experimental area and design.

At W.A.C.R.I. an area containing ten-year-old Amelonado trees planted by Benstead in straight lines at 8 ft. by 8 ft. under uniform *Gliricidia maculata* shade (24 ft. by 24 ft.) was selected for shade removal and fertilizer application. The trees were in their third year of bearing and pre-treatment records were available. Fifteen plots, each containing 300 trees, were formed. The treatments applied were: original shade with no fertilizer, original shade with fertilizer, no shade and no fertilizer, and no shade with fertilizer. The four treatments were replicated three times and each contained 900 trees, making a total of 3,600 experimental trees. These treatments were grouped in such a way that they each contained equal numbers of the different establishment methods used when the trees were planted. The three extra plots formed guard plots between shaded and unshaded cocoa. The layout of the experiment is illustrated in Fig. 1.

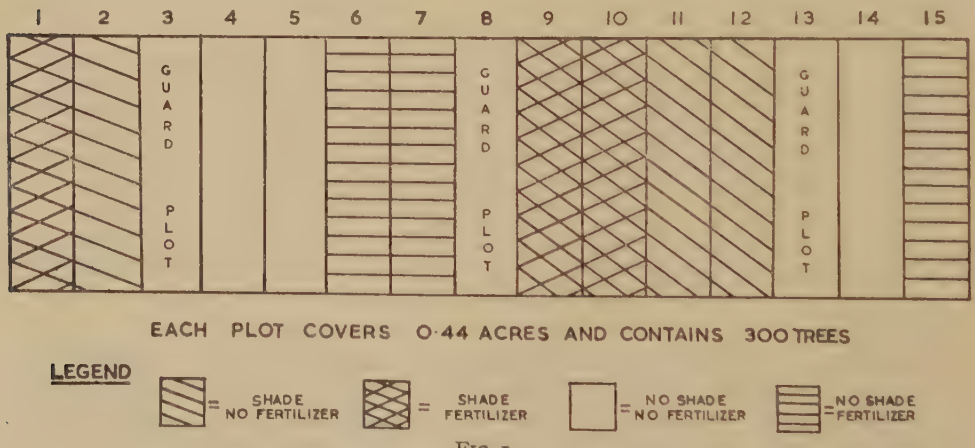
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
GUARD PLOT
GUARD PLOT
GUARD PLOT
EACH PLOT COVERS 0·44 ACRES AND CONTAINS 300 TREES
LEGEND
= SHADE NO FERTILIZER
= SHADE FERTILIZER
= NO SHADE NO FERTILIZER
= NO SHADE FERTILIZER

Fig. 1.
Plan of experiment.

Fertilizer applications.

The mean rainfall of the past 18 years at Tafo is 62·58 inches and there are two distinct annual periods. The longer begins in March–April and has its peak in July ; the shorter begins in September and has its peak in October. The dry season extends from mid-December to mid-March.

In October 1956, at the height of the small rains, the first fertilizer was applied. Table I shows the fertilizer application record to date.

TABLE I.

Scheme of fertilizer applications.

Date	Application	Fertilizers used in mixture	Rates in lb./acre			
			N	P_2O_5	K_2O	MgO
October, 1956	1	Ammonium phosphate (11% N 46% P_2O_5) Single superphosphate (18% P_2O_5) Sulphate of potash (48% K_2O) Magnesium sulphate (16·2% MgO)	13·4	90·7	90·4	45·8
April, 1957 ..	2	Urea (46% N) Triple superphosphate (47% P_2O_5)	50	30	—	—
September, 1957	3	Urea	50	—	—	—

Removal of shade.

In March–April 1957 the shade was removed from the non-shaded plots by poisoning all the shade trees with a proprietary mixture of 2, 4-D and 2, 4, 5-T. The dead trees have been allowed to stand and they have been falling during the dry season with little damage to the cocoa.

Soil.

The experiment is located on the W.A.C.R.I. soil series which is derived according to Charter (4) from hornblende granodiorite. The soil in the experimental area is a typical Ochrosol (Brammer, 3) and has developed on the top and upper slopes of the catena. In the top foot it is a well-drained sandy loam with practically no structure. Farther down the profile there is reddish brown to red kaolinitic clay with quartz gravel and ironstone concretions. The soil in each plot was sampled in February 1958, i.e. 16 months after the initial fertilizer application and 10 months after the removal of shade. The feeding roots of the cocoa tree are mainly located near the surface of the soil and only the 0–2 in. and 2–6 in. horizons were sampled. The soil analyses are given in Table II.

Table II.

Soil analyses ; each value is the mean for three plots.

Treatment	Profile	C %	N %	C/N	pH	Available P in p.p.m.*	Exchangeable bases in m.e./100 gm.			Mineralization of N† in p.p.m.		
							Ca	Mg	K	Change in NH_4-N	Change in NO_3-N	Change in total mineral N
Shade, no fertilizer ..	0–2 in.	4·37	0·341	12·8	7·48	24·1	9·01	2·90	0·54	−9·0	+94·2	+85·2
	2–6 in.	1·78	0·171	10·4	7·44	15·3	5·40	0·94	0·26	−5·6	+67·0	+61·4
Shade, fertilizer ..	0–2 in.	4·04	0·335	12·0	7·49	25·5	7·48	2·57	0·52	−12·0	+106·5	+94·5
	2–6 in.	1·83	0·183	10·0	7·46	17·6	5·14	0·87	0·27	−6·6	+67·0	+60·4
No shade, no fertilizer ..	0–2 in.	3·85	0·359	10·7	7·28	27·3	9·28	2·16	0·51	−9·4	+91·5	+82·1
	2–6 in.	1·57	0·160	9·8	7·39	16·0	5·20	1·01	0·23	−5·2	+61·2	+56·0
No shade, fertilizer ..	0–2 in.	3·56	0·297	11·9	7·22	22·5	6·74	2·29	0·42	−8·8	+93·4	+84·6
	2–6 in.	1·50	0·151	9·9	7·19	13·6	3·21	0·81	0·21	−5·0	+63·5	+58·5

* Estimated by Truog's method.

† Air-dried soil incubated for 14 days at 25° C. and 50 per cent. of its moisture-holding capacity.

Pest control.

From 1956 capsid control was effectively maintained by the use of chlorinated hydrocarbon type of insecticides applied with a knapsack type of mistblower. Black-pod control was started in 1957 with an initial application of carbide-bordeaux mixture followed at monthly intervals by Perenox.

Records and harvesting.

Seven years' measurements of height or girth and three years' of crop yields were available when the new treatments were applied. For convenience the harvest was taken as extending from 1st April to 31st March. Harvesting was carried out every two weeks and in the field only pod counts were taken. Weight of pods and of wet and dry beans were obtained from samples of 500 pods taken from each treatment. Appropriate conversion factors were calculated and the yields are presented in lb. of dry cocoa per acre.

Results.

Vegetative growth and the harvest.

For the first five months after the first application of fertilizer in October 1956 there was no visible response to that treatment. At the end of March 1957, when the

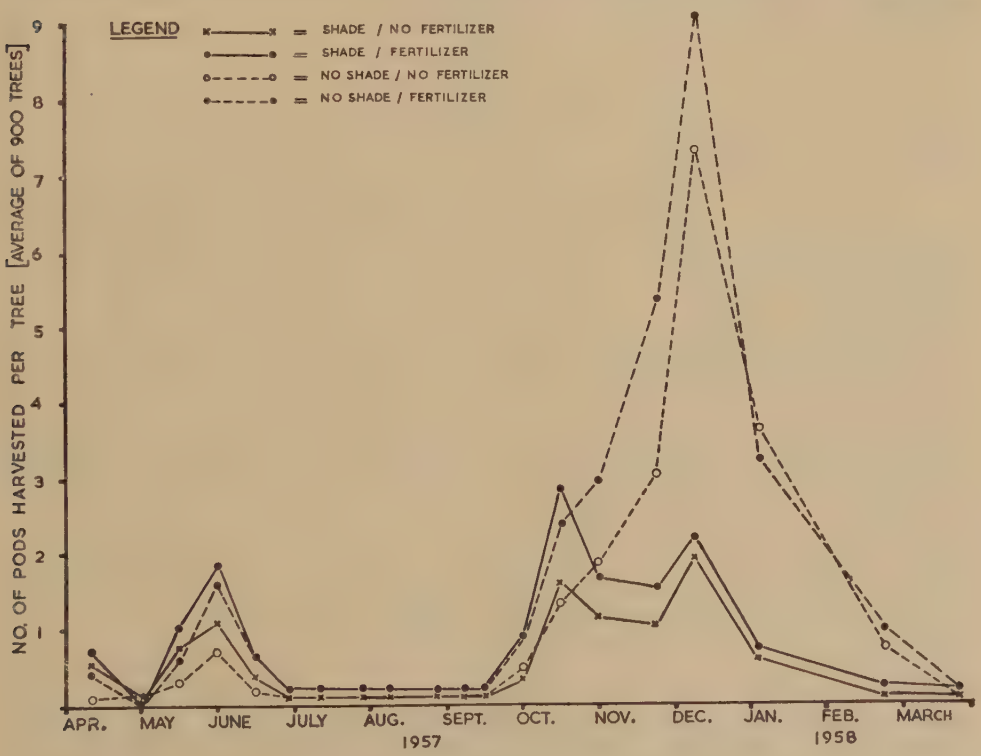

Fig. 2.
Harvest distribution.

shade on some of the plots was removed, the reaction of the cocoa was apparent at once. The trees which were exposed suffered a definite check. Young leaves wilted and there was a large discard of older leaves. The unshaded plots were immediately invaded by grasses and weeds. This setback continued until the middle of June and then the exposed trees began to recover. Even at this stage it could be seen that, in the plots which had received fertilizer, the trees were readjusting themselves more quickly than the unfertilized trees. They flushed more heavily, the canopy closed more quickly and the grass and weeds in them disappeared sooner. By the end of August the cocoa in the unshaded plots, particularly those which had been fertilized, showed no more setback symptoms.

Harvest records were made from the beginning of April. The average number of pods harvested per tree was calculated for each treatment and the seasonal yield distribution is shown graphically in Fig. 2.

The crop pre-treatment and post-treatment yields are presented in Table III.

For analysis, plots 1, 2, 5 and 6 have been grouped to make Block I, plots 4, 7, 9 and 11 to make Block II and plots 10, 12, 14 and 15 to make Block III. An analysis of covariance was carried out by the method suggested by Pearce (12), the mean of the first three years' yields being used as the independent variate. Both the recorded and the adjusted yields are shown in the Table III. Each comparison has its own standard error but for convenience only the largest standard error of a difference of means is given, viz. 86·5 (degrees of freedom, 5).

TABLE III.

Yields expressed in lb. of dry cocoa per acre.

Treatment	Pre-treatment			Post-treatment*	
	1954-55	1955-56	1956-57	Unadjusted 1957-58	Adjusted 1957-58
Shade, no fertilizer ..	30	44	205	615	586
No shade, no fertilizer ..	19	29	170	1079	1100
Shade, fertilizer ..	24	32	211	869	849
No shade, fertilizer ..	20	18	173	1574	1602

*Fertilizer mixture applied October, 1956; shade removed March, 1957.

Unfortunately, at the beginning of the season, only visual observations and harvest details were recorded. Counts of flushing, flowering, cherelle setting and wilting on several randomly selected trees in each treatment were commenced in November. The observations will be continued in future seasons. The indications from the preliminary figures are that flushing, flowering, cherelle setting and cherelle wilting follow the yield pattern with No Shade/Fertilizer followed by No Shade/No Fertilizer, Shade/Fertilizer, Shade/No Fertilizer in that order.

DISCUSSION.

No definite conclusions can be drawn from only one year's results, especially when the crop which is being studied is a perennial one. However, the main object of this fairly simple experiment was to demonstrate that it was possible, under West African

field conditions, to produce beneficial yield responses to fertilizer application and the removal of shade.

Although in future the bulk of the fertilizer will be applied in April-May, the first application was made in October to guard against any possible detrimental effects of complete shade removal. This action was subsequently justified. The mid-crop which followed the removal of shade was depressed by 52 per cent. in the Non-shaded/No Fertilizer plots ; whereas in similar plots which had received fertilizer the depression was 20 per cent. The additional nutrients had not completely compensated for the setback which followed shade removal but they did lessen the effect. It is realized that this sudden removal of shade is not good agronomic practice and it would normally have been carried out gradually over a period of possibly three seasons. The decision to remove shade in one operation was taken simply because widely contrasting degrees of shade were required quickly. It is interesting to note that, in spite of the check which the cocoa received, it recovered quickly and in four months showed no ill effects. The yields for the main crop indicated that the non-shaded cocoa had not only made a complete recovery but had outstripped the cocoa in the shaded plots. There was a similar percentage response to fertilizer under both shaded and unshaded conditions and this differs from the results obtained by comparable treatment (8 ft. by 8 ft. spacing, NPK mixture) in Trinidad (9) for the three seasons up to 1956–57. Only low responses were obtained under shade in Trinidad while the unshaded plots produced responses similar to those observed at W.A.C.R.I. For the whole season, the removal of shade produced a 88·5 per cent. increase (mean of fertilized and non-fertilized plots) compared with 45·5 per cent. increase (mean of shaded and non-shaded plots) due to fertilizer application.

From the harvest distribution graph (Fig. 2), it is apparent, especially in the main crop, that the removal of shade increased the length of the harvest period and delayed the harvest peak. Murray (10) found that increased light intensity delayed the harvest peak but claimed that the crop spread was reduced.

The soil analyses (Table II) indicate that the pH is satisfactory and the base status appears to be adequate according to Charter's (4) survey of Gold Coast forest soils. The level of available phosphorus is low (Truog extraction) but is above the average for West African surface soils given by Nye and Bertheux (11) and de Endredy and Montgomery (5). After the first year, there is no indication of any significant difference in the soil's nutrient status in the different treatments. This soil would be classified as a good Ghana cocoa soil. Support for this classification is given by the yield of the Shade/No Fertilizer plots which was 615 lb. of dry cocoa per acre in its fourth year of bearing, whereas the national average for mature Amelonado is estimated to be in the region of 250 lb. of dry cocoa per acre.

SUMMARY.

The results of the first year of a field experiment on cocoa in Ghana, involving the removal of shade and the application of a fertilizer mixture, have shown marked responses both to fertilizer and to the removal of shade. The paper does not suggest that one year's data from a field experiment give sufficient basis for drawing any final conclusions, but the sparsity of published information about the response of cocoa to agronomic treatment, especially in the major producing area for this crop, has caused the authors to report their results.

ACKNOWLEDGMENTS.

The authors wish to acknowledge that this experiment has been the result of teamwork rather than the effort of individuals. They especially wish to acknowledge the work done by Dr. P. W. Arnold, Rothamsted Experimental Station, in the initial stages of the trial. The suggestions and advice offered by Mr. T. N. Hoblyn, East Malling Research Station, when he visited W.A.C.R.I. in 1956 were extremely helpful. At various stages of the experiment help was given by other members of the W.A.C.R.I. staff. Assistance was given by Mr. A. L. Wharton who was acting Senior Agronomist at the beginning of the experiment. Mr. R. J. Benstead, Senior Agronomist, has been responsible for the harvest records and has given invaluable advice throughout. Thanks are also due to Dr. R. G. Hurd, who has begun flower-counts etc. in the various treatments, and to Mr. C. de Jonge who has checked the statistical analysis.

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THE EFFECT OF DIFFERENT IRRIGATION TREATMENTS ON THE GROWTH AND YIELD OF EARLY SUMMER CAULIFLOWERS

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To determine the best irrigation practice for a given crop it is necessary to ascertain to what extent the available water in the root zone can be depleted before growth is adversely affected. It then becomes possible to suggest an irrigation treatment, which may need to be a compromise between the optimum and that which is economically practicable. One method of determining the optimum treatment is to grow the plants in the field under known soil moisture conditions and protected from rain by movable glass shelters. Experiments to determine the response of the early summer cauliflower crop to different irrigation treatments during 1955, 1956 and 1957 are described in this paper.

In Germany, Penningsfeld (1954) and Fröhlich (1955) found that the soil moisture status must be kept above 80 per cent. of field capacity in order to obtain optimum results with early cauliflowers. Fröhlich also found that the maximum need for irrigation of this crop, harvested in June, occurred from mid-May to the end of June. In Holland, more precise measurements of water loss under glass showed that the water requirement was reduced as the curd grew larger just before cutting (Anonymous, 1953) ; furthermore, the physiological disorder causing a discoloration of the curd, known as " Waterziek ", has been shown to be related to a water shortage in the plant while the curd is developing (van den Ende, 1954).

Although the early summer cauliflower crop is often irrigated in Great Britain, there is a lack of information on the timing of irrigation, both with regard to the stage of growth of the crop and to the maximum soil moisture deficit that can be allowed to develop in the field. Secrett (1945) has recommended that irrigation should be applied only when the plants are showing definite " signs of distress " from lack of moisture and that $\frac{3}{4}$–1 inch of water should then be given.

Experimental Methods.

With certain variations, the same methods were used each year and they are described below.

Site.

In 1955 the experiment was sited on an area of alluvial sandy loam overlying gravel. At field capacity this soil held 3·3 inches of available water in the top 2 feet of soil ; full details of its moisture characteristics have been given by Stanhill (1958).

In 1956 and 1957 the experiments were sited on an area of the sandy phase of the Newport Series with light sandy loam overlying mixed sands and gravels. The moisture characteristics of this soil indicated that at field capacity the amount of available water in the top 2 feet ranged from 3·5 inches in 1956 to 3·0 inches in 1957. On both sites the water-table was well below the greatest depth of rooting.

Layout.

Each year three treatments were replicated five times in randomized blocks of plots. Every plot was surrounded by a guard row of plants. In 1955 and 1956 each plot contained thirty experimental plants at a spacing of 21 × 18 inches ; in 1957 twenty experimental plants were used at a spacing of 30 × 24 inches.

Cultural details.

Seeds of the variety Finney's 110 were sown in September of the year preceding the experiment and were pricked out into pots. After over-wintering in cold frames the plants were planted in the field in March or early April.

Treatments.

As it is impossible to maintain a constant soil moisture status around the roots of a transpiring crop (Veihmeyer, 1927), the treatments were based on the principle of varying the permitted degree of depletion of available water by evaporation and transpiration before the soil was rewetted to field capacity.

After planting, the soil of all plots was brought, by irrigation, to field capacity and then the following treatments were started :

Year	*Maximum percentage depletion of available water in the root zone of the crop*			
1955 ..	—	25	50	75
1956 ..	F.C.	—	50	75
1957 ..	F.C.	25	—	75

With treatment F.C. (1956 and 1957 experiments), the soil was restored to field capacity every day by adding an amount of water equal to that evaporated and transpired during the previous day. There was thus a maximum possible deficit of approximately 0·25 inches with this treatment, i.e. the maximum amount of evapo-transpiration recorded for a single day during the experiments. A method based on that of Penman (1948) was used to calculate the daily potential evapo-transpiration from meteorological data.

For the remaining treatments, the timing of irrigation was determined from regular gravimetric determinations of the moisture content of soil samples taken to the maximum depth of rooting at each sampling date. Whenever the desired percentage depletion of available water in the root zone of the crop had been reached, sufficient water was applied to rewet the soil to field capacity. In 1956 and 1957 the critical deficit was not reached in treatment 75, which was not, therefore, watered.

During 1955 and 1956, despite wet weather, the treatments were successfully maintained by using plot shelters described elsewhere (Winter, 1955). To minimize the effect of the glass covers on the growth of the experimental crop, the shelters were moved into position over the plots only when there was an immediate threat of rain, and they were removed entirely when harvesting was started. In 1957 the plots were left uncovered but fortunately, during the period of the experiment, there was not enough rain to interfere with the treatments to any appreciable extent.

Growth studies.

Weekly growth measurements. To determine the effects of the various treatments on growth, leaf measurements were made weekly from the time of planting to that of harvesting. The comparatively small number of plants in each plot (necessitated by the need to shelter the plots from rain) made it impracticable to use a destructive method of calculating leaf area, but the non-destructive method of calculating leaf area from leaf dimensions was found satisfactory.

In the field, four experimental plants were selected at random from each plot and the amount of leaf growth of each plant was computed at weekly intervals. The curves in Fig. 1 have been presented in the form of the sum of products of the length and breadth of all the leaves of the plant because of the progressive change in shape of the later-formed cauliflower leaves. The use of absolute values of leaf area would have necessitated the determination of new regressions regularly throughout the season to allow for the change in leaf shape.

Final growth measurements. The same person judged when each curd was ready for cutting and a record was made of untrimmed and trimmed fresh weight, leaf area, curd size and quality, for each plant.

Regressions of leaf area on leaf dimensions were determined from samples of 100 leaves at harvest, for plants from each treatment in each experiment. In 1955 and 1957 the regression equations for each treatment were not significantly different from one another. Consequently a common regression was calculated for each of these two years and was used to obtain the mean total leaf area per plant for each treatment. In 1956, however, the regressions of leaf area on leaf dimensions were significantly different for each treatment and were used individually to calculate the total leaf area of plants under the different treatments.

Experimental Results.

Results of the three experiments are summarized in Table I. The most important growth measurements made at harvest are shown, together with details of the water-regimes applied to the plants grown under the different treatments.

In 1955 the percentage of marketable curds obtained in each size grade from plants grown under treatment 25 (the maximum depletion of available water in the root zone of the crop being 25 per cent.) differed significantly from that of the corresponding plants grown under treatment 50 ; fewer large curds were produced under the wetter conditions. In this experiment, other measurements made at harvest did not differ significantly between treatments.

In 1956 highly significant differences in growth and final yield were shown by plants subjected to the different treatments. Differences in growth rate became apparent at the end of May (Fig. 1) and by harvest time the sizes of plants under the

TABLE I.

Growth data at harvest—all experiments.

Year	1955				1956				1957			
Treatment (percentage depletion of available water in root zone)	25	50	75	L.S.D. treatment means for P = 0·05	F.C.	50	75	L.S.D. treatment means for P = 0·01	F.C.	25	75	L.S.D. treatment means for P = 0·01
Mean untrimmed fresh weight (gm.)	1,394	1,482	1,436	187	1,392	1,045	539	165	1,447	1,453	916	265
Mean trimmed fresh weight (gm.)	658	705	689	64	753	602	332	72	941	975	653	93
Mean leaf area per plant (sq. cm.)	9,658	9,497	9,242	1,839	10,276	7,576	3,802	1,120	10,407	10,878	6,587	2,712
Mean area per leaf (sq. cm.)	667	642	609	100	669	468	255	91	654	680	442	97
Mean number leaves longer than 10 cm. at harvest	14·5	14·8	15·2	1·42	15·4	16·2	14·9	0·74	16·0	16·0	14·9	0·78
Percentage of total number of curds which were marketable	98	100	96	—	100	97	87	—	99	100	95	—
Distribution of marketable curds in each size grade (percentage) $3\frac{1}{2}$–$4\frac{1}{4}$ in.	30	14	19	Tr. 25 sig. diff. from tr 50 (χ^2 test : P <0·01)	3	17	61	All treatments sig. diff. from each other (χ^2 test : P <0·001)	—	—	7	Tr. 75 sig. diff. from tr. F.C. and tr. 25. (χ^2 test : P <0·01)
$4\frac{1}{4}$–5 in.	52	59	53		24	37	35		8	10	32	
5–6 in.	18	25	28		61	41	4		75	75	59	
over 6 in.	—	2	—		12	5	—		17	15	2	
Number of days from planting to 50 per cent. cut	77	76	76	—	84	82	82	—	91	90	88	—
Total amount of irrigation applied per treatment until final harvest (in.)	3·17	2·75	1·48	—	6·06	3·46	—	—	9·00	5·64	—	—
Rainfall on plots until final harvest (in.)	1·00	1·00	1·00	—	0·73	0·73	0·73	—	2·83	2·83	2·83	—

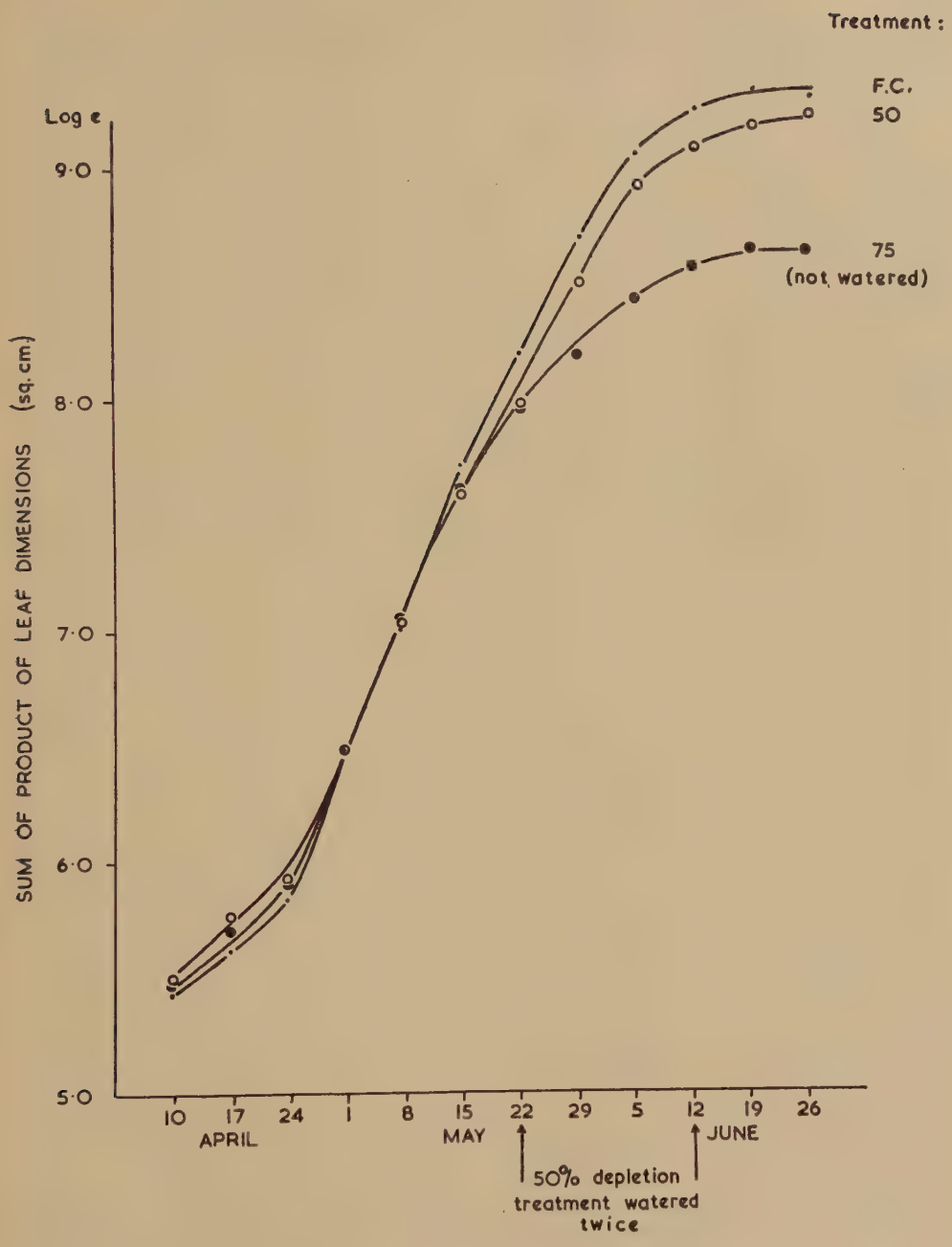

FIG. 1.

Increase in leaf area per plant under three different moisture treatments. Means of 20 plants—1956 Experiment.

three treatments differed considerably. Untrimmed and trimmed fresh weight, mean leaf area per plant and size of curd were all largest following the wettest treatment (F.C.) and there was a progressive reduction in the size of plants from the 50 and 75 per cent. depletion treatments.

Although the plants in the 1957 experiment were not protected from rain, there was little interference with the soil moisture treatments. During the period of the experiment, rainfall was well below average and, in May and June, water loss was high, necessitating a total application of 9·0 inches of water to plots under treatment F.C. Soil samples indicated that under the driest treatment the soil had been depleted of 75 per cent. of the available water by harvest time. Plants which had received this treatment had lower fresh weight and mean leaf area, and smaller individual curds, than those from the wetter treatments. There were no significant differences in growth measurements or yield of plants grown under treatments F.C. and 25.

Relationship between leaf area and curd size per plant.

To find whether the increase in leaf area, resulting from frequent irrigation, was associated with a proportionate increase in curd size, the mean leaf area per plant for each curd-size grade and treatment was determined; the data for the 1956 experiment are plotted in Fig. 2.

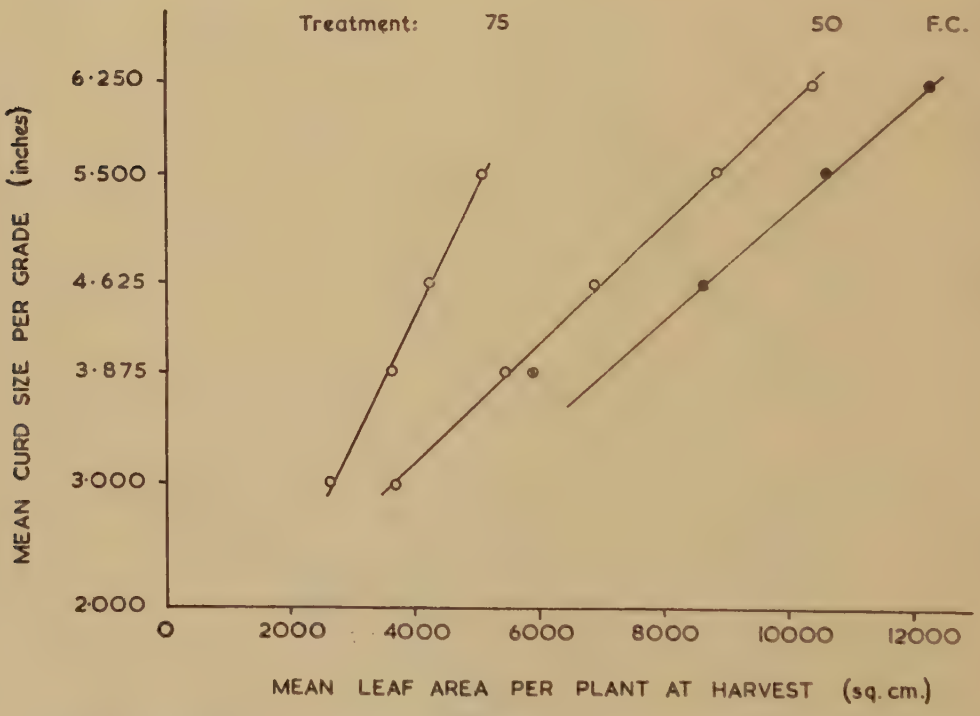

FIG. 2.

Relationship between leaf area per plant at harvest and curd size—1956 Experiment.

A linear relationship was found between the mean leaf area of plants (x) and the size (diameter) of curd produced (y). The relationship for each treatment was as follows :

Treatment F.C: $y = 0{\cdot}0004188x - 1{\cdot}9664$ $r = +0{\cdot}993$
Treatment 50: $y = 0{\cdot}0004684x - 1{\cdot}6683$ $r = +0{\cdot}999$
Treatment 75: $y = 0{\cdot}0010521x - 2{\cdot}9079$ $r = +0{\cdot}992$

The regressions were significantly different, indicating that the irrigation treatments had affected the ratio of leaf area to curd size. A similar result was obtained in 1957.

DISCUSSION.

As the 1955 experiment was carried out on a different site, only the 1956 and 1957 experiments can be directly compared. The results from these two experiments suggest that the growth of the cauliflower plant was adversely affected when 50 per cent. of the available moisture in the soil had been depleted between irrigations, but not when depletion was limited to 25 per cent. of the available moisture.

In 1956 (Fig. 1) it was seen that, on 22nd May, the available water in the soil had been depleted by 50 per cent. under treatments 50 and 75. At this date, plants grown under these two irrigation treatments were identical in size, in terms of the sum of product of leaf dimensions, but were smaller than those grown under the wettest treatment. Plots of treatment 50 were watered on this date, but with treatment 75 the soil was allowed to get drier and a further decrease in the growth rate occurred relative to that in the wetter treatments. On 12th June plots under treatment 50 were again irrigated ; nevertheless, measurements at harvest showed that this treatment had adversely affected growth compared with the wettest treatment (F.C.). The 1957 results, however, indicated that daily watering was not necessary to produce the highest yield and showed that at least 25 per cent. of the available soil moisture could be depleted without any adverse effect on the crop. It should be noted that the plant spacing in 1957 was different to that in 1955 and 1956 and this fact may have influenced the result.

The measurements made at harvest in 1956 and 1957 show that the fresh weight and leaf area responded to the treatments in the same way as total yield. The size of the individual leaves was reduced when 50 per cent. or more of the available water was depleted before irrigation was applied. In 1956 the leaf shape was affected by the treatments, resulting in significantly different regressions of leaf area on leaf dimensions. Under the drier treatment the leaves were smaller and were strap-shaped, in contrast to the large broad leaves produced under the wet treatment.

The percentage of curds marketed was high from plants of all treatments but the distribution in size grades was significantly affected by the irrigation treatments. The dry treatments, in general, produced a higher percentage of plants with small curds. Frequent irrigation appeared to delay maturity by two or three days.

Results of the first year's experiments in 1955 were not in agreement with those of 1956 and 1957 ; mean plant weight and leaf area per plant were not influenced by the treatments and curd size was adversely affected by the wettest treatment. The failure to obtain a response to the different treatments in this year may have been caused by the continuous wet weather during the growth of the crop. Although the crop was protected from rain, the rate of water loss was comparatively low.

Under such conditions the growth of the roots into the deeper layers of soil may have been sufficiently rapid to prevent soil moisture from becoming limiting, thus making the plants independent of surface applications of water. This hypothesis has been suggested by Majmudar and Hudson (1957) to explain the lack of response to irrigation by a crop of lettuce grown under glasshouse conditions. Stanhill (1958), however, has shown that this explanation did not apply to the turnip crop under the conditions of his experiments.

In Fig. 2 it is shown that, for each of three different irrigation treatments, there was a close linear relationship between the mean curd size of each grade and the mean leaf area of the plants producing that size of curd. The larger the leaf area of the plant, the larger was the curd produced. However, the relationship differed for plants grown under the different treatments. A similar-sized curd was produced by a small plant under dry conditions and by a larger plant grown under wet conditions. Thus the linear relationship between curd size and leaf area has been altered by the different soil moisture treatments.

The results of the experiments do not support Veihmeyer's hypothesis that soil moisture is equally available to plants between field capacity and the permanent wilting point (Veihmeyer and Hendrickson, 1950), but agree with the conclusions of a recent review (Stanhill, 1957) that the degree of depletion of available water in the soil does affect the growth of many crop plants.

Further work is in progress to determine whether there is any particular period during the growth of the crop when wet or dry conditions are especially beneficial. For example, it has been stated that irrigation is not necessary after the ground is covered by foliage (Ministry of Agriculture and Fisheries, 1952). This statement has not been substantiated by experimental work and indeed the evidence so far available is to the contrary (Fröhlich, 1955).

The results of these experiments suggest that more than 50 per cent. of the available soil moisture should be present in the root zone of the early summer cauliflower crop from planting time to harvest, otherwise yields will be adversely affected.

SUMMARY.

Three experiments are described in which the response of early summer cauliflower plants to different soil moisture conditions in the field was determined. Two of the experiments were protected from rain by movable shelters. In the different treatments, water was applied daily, or 25, 50 or 75 per cent. of the available soil moisture was allowed to be depleted before the plots were irrigated. At least 25 per cent. of the available soil moisture could be depleted before irrigation was required to maintain maximum growth rate. It was unnecessary to maintain the soil at field capacity to obtain maximum yields. For each treatment a close linear relationship was found between leaf area and curd size of plants at harvest. This relationship differed between treatments.

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APPLE ROOTSTOCK STUDIES: THIRTY-FIVE YEARS' RESULTS WITH WORCESTER PEARMAIN ON CLONAL ROOTSTOCKS

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THIS rootstock trial was one of those planted by Hatton at East Malling during the period 1920–22. It comprised sixteen clonal rootstocks, M.I–M.XVI, and the vegetatively raised Free stocks, Crabs E, F and G8. This paper presents growth and cropping data for a thirty-five year period, from 1920 to 1954 inclusive, for thirteen of these rootstocks. Six of the more important, namely M.I, M.II, M.IV, M.VII, M.IX and M.XVI, are discussed in greater detail. In the many years during which this trial has been in progress there have been marked changes in fruit-growing practices, so that it is hardly surprising that it also has undergone differing cultural treatments. These changes are fully set out in the following section and the figures given in the tables are associated with these cultural changes unless otherwise stated.

Plot history.

The trees were planted as maidens in January 1920, on a sandy loam of the Malling Series (Furneaux, 1954). Worcester Pearmain and Bramley's Seedling trees alternated in each row at 15 feet apart, and during the early years there was intercropping with soft fruit.

For the first eight years the Worcester trees on the south half were unpruned after heading back at planting, while those on the north half were long spur-pruned; thereafter all trees were long spur-pruned, with leader tipping becoming progressively lighter with age until the twenty-sixth year when trees on the more vigorous rootstocks, M.XII, XIII, XV and XVI, were pruned by the renewal method (Thompson, 1949).

The whole trial was grassed down in the twelfth year. In the twenty-third year the grass on the north half was ploughed and kept clean cultivated until it was resown with grass in the thirty-fourth year.

Differential nitrogenous manuring was begun in the fifteenth year, half the trees on each rootstock receiving a dressing of Nitro-chalk at 5 cwt. per acre annually until the seventeenth year. The remaining half of the trees received a single application of 15 cwt. of Nitro-chalk per acre in the fifteenth year. Thereafter these treatments ceased and manuring was uniform.

The Bramley trees were removed in the sixteenth year and a year later some trees of Worcester Pearmain were moved from another plantation into the Bramley positions. Trees of James Grieve, twenty-two years old, were interplanted in the seventeenth year to give a pollinator ratio of 1 : 10. The transplanted Worcester trees were removed in the thirty-first year and the spacing of the permanent trees was thus increased to 21 feet.

During the period 1952–54 all trees were tested for rubbery wood and apple mosaic viruses. The double-budding method described by Posnette and Cropley (1954) was used and the resulting scions were tested for rubbery wood by the hand-bending method (Prentice, 1950). There were no symptoms of rubbery wood visible on the parent trees. These tests, however, showed that 13 per cent. of the trees were infected with rubbery wood virus. The numbers of trees infected on each rootstock are shown in Table I. Of the thirteen trees infected, five had smaller areas of trunk cross-section and gave lower crops than the healthy neighbouring trees on the same rootstocks and five trees showed no effect of rubbery wood upon these characters. An apparent effect of virus on crop, but not on area of trunk cross-section, was shown on two trees and the converse was shown by one tree. The effects were not clear-cut; thus one infected tree on M.XV showed an apparent effect upon both characters whereas the other one showed no effect. With trees on the six rootstocks reported in detail, only one on M.IV and three on M.IX were infected. In these four trees the infection seems to have had no effect upon growth and cropping. Thus the fact that there were two trees on M.IX smaller than the remaining six could not be accounted for on grounds of virus infection. The tests showed that no tree was infected with apple mosaic virus.

When recently inspected the trees were found not to be scion-rooted.

Layout.

Trees on each rootstock were distributed in equal numbers in the north and south halves of the trial with the exception of those on the six rootstocks, M.VIII, XI, XIV, and Crabs E, F and G8, which occurred in the central five rows as did also four trees on M.XVI. A plan of this layout has already been published (Anon., 1924). The grassed and clean-cultivated halves of the plantation met among the trees on these rootstocks. Owing to the possibility of an edge effect upon these trees, due to the junction of the grassed and clean-cultivated halves and to their poor distribution over the planted area as compared with trees on other rootstocks, data from these trees have been omitted from the results.

The trial was not designed for statistical analysis and significant differences are not given, but the number of trees planted on each rootstock has helped to make the main contrasts clear.

Results.

A summary of the growth and cropping of trees on thirteen rootstocks up to the thirty-sixth year is shown in Table I ; it is based upon the means of eight trees on each rootstock, except for M.XVI on which there were four trees. Half the trees on each rootstock were unpruned during the early years and these were grassed down in the twelfth year. These are referred to as "unpruned" trees.

Area of trunk cross-section.

The mean area of trunk cross-section at thirty-five years of age confirms the vigour groups into which trees on the six main rootstocks have normally fallen in other trials, *viz.* M.IX dwarfing, M.VII semi-dwarfing, M.IV moderately vigorous, M.I and M.II vigorous, and M.XVI very vigorous (Table I). Trees on these rootstocks established their relative order when fifteen years old after which there was no

TABLE I.

Summary of growth and cropping of Worcester Pearmain on thirteen clonal rootstocks.

Rootstock	Mean area trunk cross-section (sq. cm.) at 35 years	Total crop per tree (bushels*) at 35 years	Ratio of crop (lb.) to cross-section area (sq. cm.)	Number of trees infected with rubbery wood virus
M.I	338	92	10·9	0
M.II	366	105	11·4	0
M.III	363	95	10·4	1
M.IV	302	101	13·4	1
M.V	396	105	10·6	3
M.VI	435	86	7·8	2
M.VII	237	66	11·1	0
M.IX	126	45	14·2	3
M.X	356	74	8·2	0
M.XII	618	118	7·6	1
M.XIII	594	110	7·4	0
M.XV	492	93	7·5	2
M.XVI	594	122	8·2	0

* 1 bushel = 40 lb.

change (Table II). There was little difference between pruned and "unpruned" trees in the order of rootstocks. The "unpruned" trees were larger than the pruned ones during the first ten years, and also at fifteen and twenty years of age, with the single exception of those on M.XVI. The "unpruned" trees on M.II and M.IX remained larger than the pruned ones throughout the period of the trial.

TABLE II.

Order of rootstocks for trunk cross-sectional area and accumulated crop per tree.

	Tree size (trunk cross-sectional area)			Accumulated crop						
Age	10	15	35	5	10	15	20	25	30	35
Smallest	IX	IX	IX	VII	IX	IX	IX	IX	IX	IX
	VII	VII	VII	I	VII	VII	VII	VII	VII	VII
	I	IV	IV	II	XVI	XVI	XVI	XVI	I	I
	II	I	I	XVI	II	II	I	I	IV	IV
	IV	II	II	IV	I	I	II	IV	II	II
Largest	XVI	XVI	XVI	IX	IV	IV	IV	II	XVI	XVI

Height and spread.

Mean tree height and area of branch spread (mean spread diameter squared), as further measures of tree size, agree well with area of trunk cross-section. Trees on M.IV were as large as those on M.XVI in the tenth year and the order of rootstocks in the fourteenth year was identical with that in the thirty-sixth (Table III). The figures for the trees at seventeen years of age showed an effect of overcrowding from the Bramley trees that had been removed two years earlier.

TABLE III.

Tree height (m.) and area of spread (sq. m.).

Age	9		13		17		36	
Rootstock	Height	Area	Height	Area	Height	Area	Height	Area
M.IX	1·9	5·8	2·6	7·3	2·5	10·9	3·2	16·8
M.VII	2·8	8·4	3·4	10·9	3·3	16·0	3·8	24·0
M.I.	3·0	9·0	3·9	13·0	4·0	20·3	3·9	26·0
M.IV	3·2	10·2	3·9	13·7	3·8	23·0	4·0	29·2
M.II	2·9	9·0	3·9	14·4	3·9	22·0	4·1	29·2
M.XVI	3·4	10·2	4·4	16·8	4·9	27·0	5·1	56·3

Accumulated crop.

During the trial there were several changes in the relative order of rootstocks in respect of accumulated crop (Table II) but by the twenty-fifth year the order had become established, with the exception of trees on the very vigorous M.XVI. At five years, trees on the dwarfing M.IX had yielded the heaviest crops but during the next three five-year periods the heaviest crops were borne by trees on the moderately vigorous M.IV. There was little difference between the total crop of trees on M.IV and M.II at the end of the twenty-fifth year (10 lb.) but this difference increased up to the thirty-fifth year (137 lb.).

The " unpruned " trees cropped more heavily than the pruned ones throughout the trial, with the single exception of trees on M.XVI during the last five-year period (100 lb. per tree). The figures from trees on rootstocks in two distinct vigour groups, M.IX and M.II, show that these differences were considerable (Table IV).

TABLE IV.

Accumulated crops (lb.) from pruned trees (P) and trees unpruned during the early years (U), on two rootstocks.

Age		5	10	15	20	25	30	35	% increase U over P
M.IX ..	P	4	107	264	447	709	1,165	1,584	
	U	19	203	454	755	1,061	1,552	1,998	26
M.II ..	P	4	145	491	1,173	1,827	3,033	3,956	
	U	9	209	577	1,256	1,967	3,288	4,432	12

TABLE V.

Heaviest crop per tree and age at which it was borne.

Rootstock	M.IX	M.VII	M.I	M.IV	M.II	M.XVI
Heaviest crop (lb.) ..	111	174	263	278	288	372
Age	27	27	28	27	27	29

Trees on most rootstocks bore their heaviest crop at twenty-seven years of age (Table V), the heaviest crops from trees on M.I, M.II and M.IV being very similar.

Fruit size.

Fruit size records, made during the eight-year period 1943–50 inclusive when the trees were mature (24–31 years old), are summarized in Table VI. Trees on M.IX bore the largest fruits. During this period the " unpruned " trees were under grass and the pruned trees had been clean-cultivated since 1941. Trees under grass bore slightly larger fruits than did those in clean cultivation when the rootstocks were M.I, M.II, M.IV and M.IX; the reverse applied to trees on M.VII and M.XVI though the difference for trees on M.VII was negligible.

TABLE VI.

Fruit size. Mean weight per 100 fruits (lb.).

Rootstock	M.IX	M.VII	M.XVI	M.II	M.IV	M.I
Mean for 1943-50 ..	19	17	17	16	16	16

Crop in relation to tree spacing.

Estimated yields per acre, based on the accumulated crops at three periods during the trial and on an estimate of the planting distances required by trees of Worcester Pearmain on six rootstocks at thirty years of age, are shown in Table VII. Trees on M.XVI, under the conditions of soil and management in this trial, would have been overcrowded at 24 feet apart at thirty-five years of age ; nevertheless, the distances shown in the table provide a comparison of this variety with Lane's Prince Albert and Cox's Orange Pippin at the same distances and periods of development (Preston, 1958a, 1958b).

TABLE VII.

Estimated cumulative yields per acre in bushels at appropriate spacing for trees on six clonal rootstocks.*

Rootstock	Distance apart in feet	Number of trees per acre	Estimated cumulative yields					
			10 years		20 years		30 years	
M.IX ..	12	302	M.IX	1,170	M.IV	4,811	M.IV	11,704
M.VII ..	15	193	M.IV	863	M.IX	4,538	M.IX	10,253
M.IV ..	17	150	M.VII	762	M.VII	3,850	M.VII	9,607
M.I ..	20	108	M.I	497	M.II	3,281	M.II	8,532
M.II ..	20	108	M.II	478	M.I	3,227	M.I	7,668
M.XVI ..	24	75	M.XVI	328	M.XVI	2,169	M.XVI	6,323

* 1 bushel = 40 lb.

Trees on the dwarfing M.IX had yielded, during the first ten-year period, 2½ times more fruit per acre than trees on the very vigorous M.XVI ; but during the second ten-year period the difference was only 83 per cent. and in the third ten-year period 38 per cent.

Bearing in mind the limitations of this method of estimating yields on an acreage basis, the figures show that the order of rootstocks based upon accumulated crop per tree (Table II) may be considerably modified on a per-acre basis (Table VII), and they illustrate the possibilities of using more than one rootstock in orchard planning.

GENERAL DISCUSSION.

This paper is the last of three (cf. Preston, 1958a, 1958b) that have considered the field performance of three scion varieties in some of the oldest clonal rootstock trials planted by Hatton at East Malling during the period 1920–22. Trees of a fourth variety, Bramley's Seedling, in a trial reported by Hatton (1935), are now very largely scion-rooted and valid comparisons can no longer be made. The three papers show that, whereas each scion variety has given characteristic effects upon growth and cropping, the relative effect of different rootstocks has been substantially the same.

The relative order of rootstocks for tree size was established by the fifteenth year for all three varieties, Worcester Pearmain, Cox's Orange Pippin and Lane's Prince Albert. The order for cropping, established in the twentieth year with trees of Lane's, was established five years later with Worcester and Cox, with the exception of trees on M.XVI which fell into their present position in the thirtieth and thirty-second years respectively.

The value of light pruning in securing earlier cropping has been demonstrated in recent apple rootstock trials (Preston, 1955), especially with trees on the more vigorous rootstocks. In this trial, the persistent effect of no pruning at all during the early years upon the growth and cropping of half the Worcester trees, even after all trees had been pruned alike from the ninth year, shows that this work could be reduced even further with some varieties. It is important to realize, however, that the naturally compact habit of growth of Worcester Pearmain makes early tree shaping less important than with a weaker variety, such as Cox's Orange Pippin, where absence of early pruning might prove disastrous.

Cropping figures, based upon estimated acreage yields for trees on different rootstocks at appropriate spacing, favour trees on rootstocks of dwarfing or intermediate vigour over a thirty-year period. Where soil and growing conditions are favourable such trees, being relatively small and closely spaced, may well prove to be more economic and more easily managed than those on more vigorous rootstocks.

SUMMARY.

The growth and cropping of Worcester Pearmain on thirteen clonal rootstocks, up to the age of thirty-five years, are reported. Trees on Malling IX, M.VII, M.IV, M.I, M.II and M.XVI are dealt with in detail.

The relative order for the six main rootstocks for tree size was established by the fifteenth year. The order for cropping was established by the twenty-fifth year, with the exception of trees on M.XVI which fell into their present position five years later. Trees on most rootstocks bore their heaviest crop at or about the twenty-eighth year.

Half the number of trees on each rootstock were unpruned during the first eight years, after initial heading back. Henceforth all were pruned alike. The

"unpruned" trees were larger than the pruned ones during the first ten years, and during the next ten years with the exception of trees on M.XVI. The "unpruned" trees produced the heavier crops throughout the trial with the exception of those on M.XVI during the last five-year period.

Estimated acreage yields are shown, based upon accumulated crop per tree at appropriate spacing for trees on different rootstocks. These favoured trees on rootstocks of dwarfing and intermediate vigour.

The results are discussed in relation to those reported earlier for Lane's Prince Albert and Cox's Orange Pippin on similar rootstocks.

ACKNOWLEDGMENTS.

This experiment was initiated by Sir Ronald Hatton who was assisted by the late Mr. Jesse Amos until 1945. Mr. T. N. Hoblyn was responsible for many of the earlier calculations and his experience has been very valuable to the author. Many past and present members of the Pomology and Statistics Sections have assisted in securing and summarizing data. Dr. A. F. Posnette and Mr. R. Cropley carried out the virus tests. The help of all these is gratefully acknowledged.

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FURTHER STUDIES ON THE INFLUENCE OF FUNGICIDE SPRAYS ON THE BALANCE OF PHYTOPHAGOUS AND PREDACIOUS MITES ON APPLE IN SOUTH-EAST ENGLAND

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THE importance of the fungicide used for Apple Scab control in affecting the development of harmful populations of the Fruit Tree Red Spider Mite, *Metatetranychus ulmi* (Koch)*, has been noted by Gilliatt (1935), Cutright (1944) and Pickett *et al.* (1946). The advent of the relatively specific organic fungicide glyodin (Chandler and Thurston, 1949) offered a hope of scab control with a minimum of side-effects on arthropod populations and hence of assessing the rôle of predators in the control of *M. ulmi*. In a preliminary trial in Kent (Collyer and Kirby, 1955), on plots sprayed with one or another of four fungicides in 1951–3, higher populations of *M. ulmi* developed following lime sulphur sprays than after glyodin or captan ; wettable sulphur gave an intermediate result. Conversely, higher populations of predacious mites (*Typhlodromus* spp.) were present on glyodin- or captan-treated trees than on trees receiving lime sulphur. No apparent differences in populations of predatory insects resulted from the four fungicide treatments, and the tentative conclusion was drawn that in this experiment these insects were less likely than the predacious mites to be a cause of the markedly different *M. ulmi* populations. However, as the plots were small and the trees very close, any differences in insect numbers caused by the treatments would soon be adjusted. A second large-scale trial was made at a more suitable site at Mellow Purgess Farm, Stondon Massey, near Brentwood, Essex in 1952-6, where plots were much larger, allowing several guard rows, and the trees were much younger and smaller, facilitating thorough spraying and representative sampling. Also, this relatively isolated orchard had received very few spray applications in the past and had never suffered from mite infestations at an economic level; *Typhlodromus* mites and several insect predator species were already present.

MATERIALS AND METHODS.

Materials.

Three treatments—A, B and C—were applied four times in each year, in threefold replication ; A and B were unchanged throughout the five years, but C was changed twice.

* Since this paper went to press, it has been agreed that the name *Panonychus ulmi* (Koch) must take precedence.

A. Lime sulphur, 2·5 per cent. and 2 per cent. pre-blossom, 1 per cent. and and 0·75 per cent. post-blossom.

B. Captan (N-trichloromethylthio*cyclo*hex-4-ene-1 : 2-dicarboxyimide), 0·1 per cent. throughout.

C.
- 1952: Glyodin (2-heptadecylglyoxalidine acetate), 0·075 per cent. throughout.
- 1953-5: Lime sulphur, 2·5 per cent. and 2 per cent. pre-blossom; captan, 0·1 per cent. twice, post-blossom.
- 1956: DNOPC (2-(1-methyl-*n*-heptyl)-4 : 6-dinitrophenyl crotonate), 0·025 per cent. throughout.

The lime sulphur was a standard commercial product, containing approximately 25 per cent. (w/v) polysulphide sulphur. Captan was used as a 50 per cent. wettable powder. Glyodin was put into the spray tank as a 34 per cent. solution in *iso*-propanol; the base was then set free by adding hydrated lime (½ lb. per 100 gallons final dilution) to the partly diluted wash. The DNOPC was used as a nominal 25 per cent. wettable powder; a small part of the active ingredient would have been present as the free phenol.

Before 1952 the only insecticide applied had been tar oil; no lime sulphur had been applied. During the years of the trial, insecticides were kept to a minimum; nicotine or lead arsenate was applied at the standard rate when necessary to control aphids, sawfly, and caterpillars. Little damage from pests or diseases occurred throughout the trial, apart from some caterpillar feeding and some powdery mildew on the captan-treated trees. It was necessary to apply DDT in 1953 and 1955 against Apple Blossom Weevil; a wettable powder was used in 1953 and a miscible preparation, with more success, in 1955. All spraying dates for the five years are given in Table I.

TABLE I.

Stondon Massey trial; dates of spraying, 1952–6.

	1952	1953	1954	1955	1956
Fungicides	17th April	15th April	22nd April	21st April	24th April
	29th April	2nd May	7th May	3rd May	8th May
	14th May	21st May	24th May	23rd May	25th May
	29th May	3rd June	11th June	10th June	13th June
DDT	—	1st April	—	12th April	—
Nicotine	17th April	8th May	9th and 22nd April	—	25th May
Lead arsenate	23rd April	8th May	—	—	1st May

Layout.

The experimental orchard, consisting of 460 young Cox's Orange Pippin trees in arable, with Worcester Pearmain pollinators distributed irregularly, was roughly

square and surrounded on three and a half sides by trees and hedgerows, the remainder of the fourth side adjoining other orchard trees. It was divided into nine approximately square plots of up to 64 trees ; the four centre trees of each plot, used for recording mite populations, were separated from those of the neighbouring plots by four-six rows of trees.

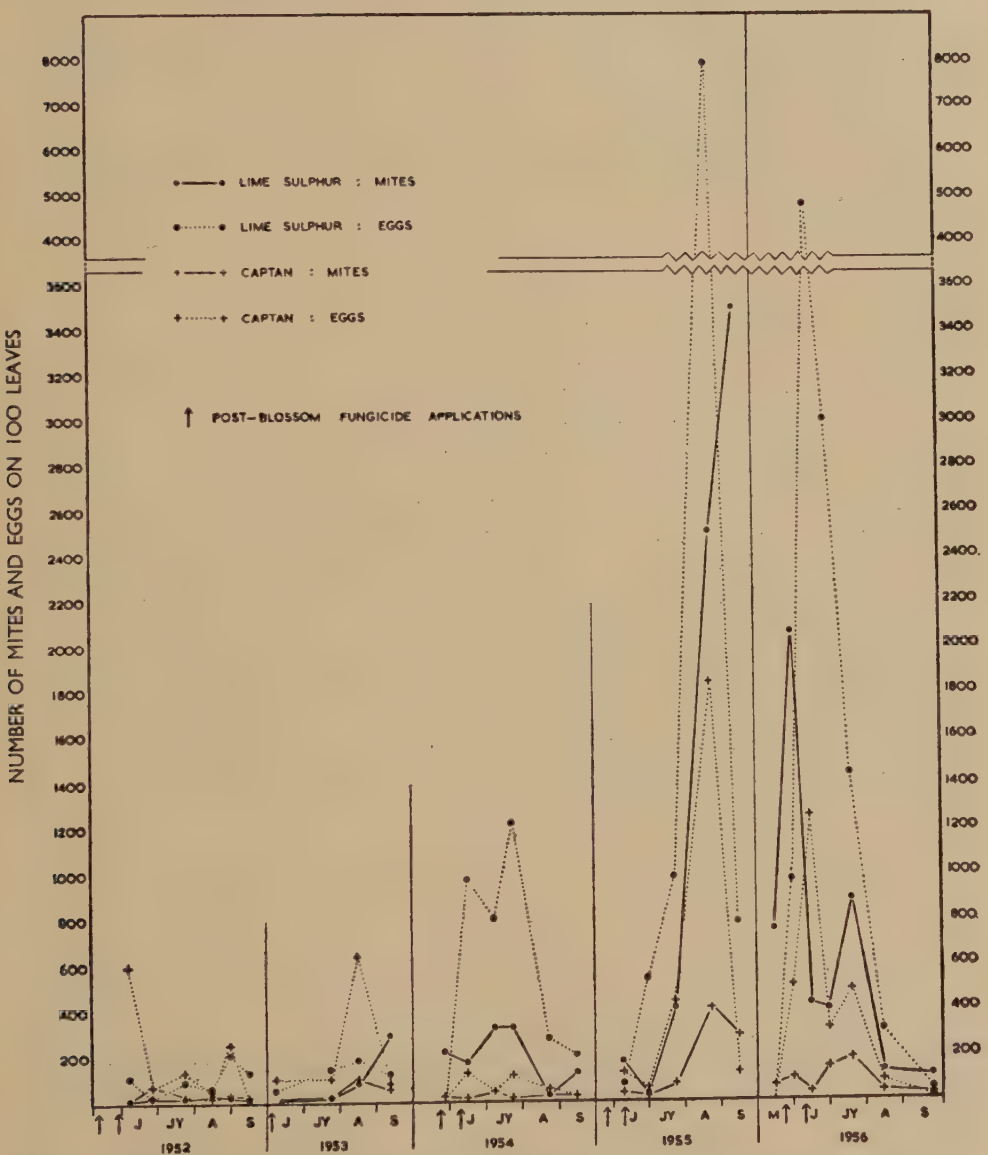

FIG. 1.

Population densities of *M. ulmi*, mites and summer eggs, for the two principal treatments in the trial at Stondon Massey, Essex, 1952-56.

Procedure.

Sprays were applied by lance with a commercial machine at approximately 300 lb./sq. in. pressure. No screens were used ; when the wind was strong enough to cause serious drift, the leeward row of each plot was either left unsprayed or sprayed with the material used on the plot to leeward.

After 1952, when the imprint method of recording *M. ulmi* was used, numbers of all mite species were recorded by the brushing machine (Henderson and McBurnie, 1943). Usually a sample of 25 leaves, omitting either very young or very old ones, was collected at random from each recorded tree, making a total of 100 leaves per plot and 300 leaves per treatment.

To avoid interfering with the mite counts, predacious insects were recorded, by tapping up to 48 branches over a beating-tray, on trees surrounding the four in each plot on which mites were recorded. Fig. 3 shows the results, expressed in each case for 48 branches.

RESULTS.

Fluctuations in the densities of M. ulmi *populations.*

Fig. 1 gives numbers of mites and eggs of this species for the lime sulphur and captan treatments throughout the five years.

Throughout 1952 mite numbers remained below one per leaf and differences between treatments did not reach a significance of $P = 0{\cdot}05$, but in early June, though not later, there were more summer eggs on captan-treated than on lime sulphur plots. In 1953 mite numbers were at first low on all plots and no differences emerged until September, when the density on lime sulphur plots exceeded one mite per leaf for the first time; this was the first sign of the pattern, namely higher mite numbers on lime sulphur than on captan plots, that was established early in the Kent trial and was to continue for the rest of this trial. Egg numbers were low and similar for the two treatments, except on 11th August when the captan plots had three times as many as the lime sulphur plots ; nevertheless, the mite population density rose subsequently only on the latter, indicating a possible effect of the relative populations of predacious mites (*vide infra* and Fig. 2).

Larger differences in both mite and egg numbers were recorded in 1954. The initial (25th May) mite records reflected the position at the end of 1953. Many more

TABLE II.

Temperature and rainfall records taken in the district during the five years of the experiment.

	1952		1953		1954		1955		1956	
	M.T.	Rf.	M.T.	Rf.	M.T.	Rf.	M.T.	Rf.	M.T.	Rf.
May	66·4	1·28	64·3	1·42	61·5	1·64	59·2	4·18	65·7	0·51
June	70·6	2·26	66·2	1·29	65·7	2·73	67·0	2·31	64·2	1·49
July	74·0	0·73	69·0	3·48	66·4	2·49	73·5	0·27	68·7	3·65
August	73·0	1·98	71·0	1·38	67·5	3·44	74·5	0·47	65·3	3·63
September	61·2	2·88	66·4	2·71	66·4	1·84	67·3	2·58	66·0	1·40

M.T. = mean of maximum temperatures, ° F.
Rf. = total rainfall, inches.

eggs were laid by the larger number of first-generation mites present on the lime sulphur plots, leading to a still larger difference ($P < 0{\cdot}05$) in mite population densities by 7th July, which only disappeared late in August and was reappearing by mid-September. The diminution on all plots in August may have been due to general predatory insect activity, but it is probable that the relatively cool, very wet weather played a considerable part (Table II).

In 1955 mite densities on the lime sulphur plots increased throughout the season, reaching 35 per leaf in mid-September compared with 3 per leaf on the captan plots. Bronzing of the foliage first occurred in that year ; it was seen on two of the three plots receiving a full lime sulphur schedule, particularly on Worcester Pearmain. Egg numbers on lime sulphur plots reached about 80 per leaf by 23rd August ; this accounts for the further increase in mites on lime sulphur plots that was recorded in mid-September.

Following the mite infestation of autumn 1955, the lime sulphur plots showed dangerously high numbers (8 per leaf) in mid-May, 1956 ; much lower ($P < 0{\cdot}05$) populations were then present on captan trees and they remained low throughout the season. Populations on lime sulphur plots went up to 20 per leaf by the end of May, but then fell as sharply to one per leaf by mid-August. They were even lower later in the year, but nevertheless remained significantly higher ($P<0{\cdot}05$) than on captan plots. However, it is difficult to assess the relative importance, as controlling factors, of the large populations of predatory insects present and of the weather which resembled that of 1954 and differed markedly from that of 1955 (Table II).

Considerable interest attaches to the data for the third treatment. Glyodin was used only in 1952, when the overall effect was similar to that of captan, as in the Kent trial. In 1953, when glyodin was replaced by pre-blossom lime sulphur/post-blossom captan, no difference appeared in either mite or egg population densities for any treatment up to 21st July (cf. Fig. 2). The numbers of eggs on the mixed-schedule trees on 11th August were intermediate between those on the other two treatments, but were fewest of all by 10th September ; mite numbers in August remained lower than on the other treatments and by 10th September were at the same level as those for the captan plots, while those on lime sulphur plots were rising sharply. In 1954 densities on the mixed-schedule plots were always intermediate, although the final mite figure was much nearer that for lime sulphur than that for captan plots. In 1955 intermediate values were again obtained, but generally closer to those on lime sulphur plots than in 1954 ; again the final mite figure (15th September) was much nearer to that for lime sulphur plots, showing a sharp increase over the previous record (23rd August), whereas the density on the captan plots fell over the same period.

The result of using lime sulphur pre-blossom in place of captan was an increase of *M. ulmi* approximating to that which follows a complete programme of lime sulphur. Consequently, it appears that the 2-2½ per cent. pre-blossom lime sulphur sprays are mainly responsible, even for divergences of mite population densities which developed at the ends of the seasons. As the mixed-schedule treatment was begun a year later than the full schedule of lime sulphur, the close similarities in densities on these two treatments in 1955 are all the more impressive.

The introduction of DNOPC in 1956 coincided with a cool wet summer, but the records taken on 31st May, when the mite numbers equalled those for the captan plots and the egg numbers were even lower, show that it was acting as a much more

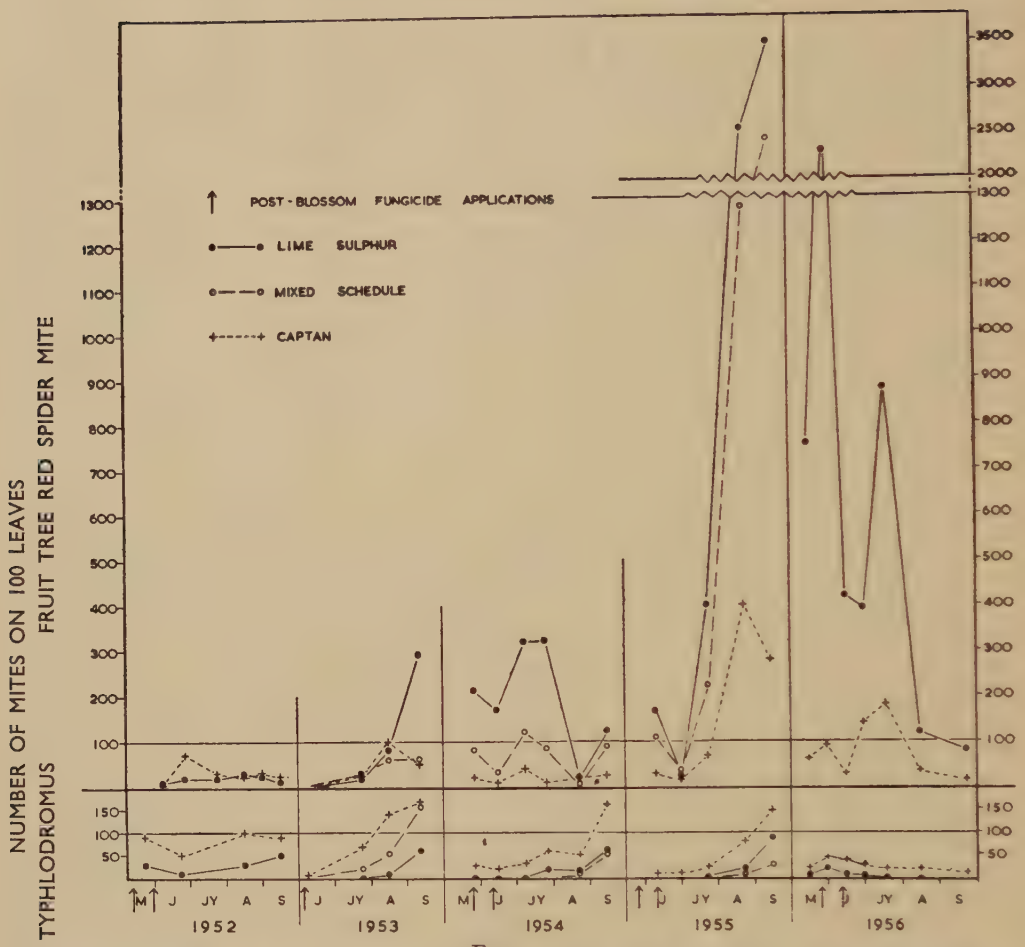

FIG. 2.

Population densities of *M. ulmi* (above) and *Typhlodromus* (below), mites only, for the two principal treatments, 1952-56, and the mixed-schedule treatment, 1953-55, in the trial at Stondon Massey, Essex.

efficient acaricide than was lime sulphur. These numbers remained low throughout the season and similar to those on captan plots.

Fluctuations in the densities of predacious mite populations.

The choice of this orchard was largely determined by the abundance of predacious mites (*Typhlodromus tiliae* Oudms.), present at a density of at least one per leaf before the start of the experiment. Fig. 2 gives records of *T. tiliae* for the five years, with those of active stages of *M. ulmi* for comparison. In all years except 1956, this mite reached or exceeded the density of one mite per leaf by August or early September on captan-sprayed trees, and in 1952 on glyodin-sprayed trees.* The lime sulphur

* Parent *et al.* (1956) found lower populations of *M. ulmi* and higher of *Typhlodromus* on trees sprayed with glyodin than on trees sprayed with elemental sulphur, especially colloidal sulphur.

schedule reduced the density to less than half of that on captan trees in spring and summer. Some recovery took place later in the season, but in all years there were more *Typhlodromus* on captan than on lime sulphur trees, the significance level failing to reach $P < 0{\cdot}01$ only in 1952, in June and September, 1953, and on the last two occasions in 1955. As before, the mixed schedule showed a preponderant influence of the pre-blossom treatment ; in 1953, following glyodin spraying in 1952, the density of *Typhlodromus* followed an intermediate course, but in 1954 and 1955 it remained very similar to that on lime sulphur trees, i.e. significantly less than on captan trees. The use of captan post-blossom apparently does not assist these mites to recover from pre-blossom lime sulphur applications. The use of DNOPC in 1956 resulted in populations of *Typhlodromus* very similar to those on lime sulphur trees, showing a detrimental effect of this material ; Morgan *et al.* (1958) found this chemical to be toxic to *Typhlodromus* spp., but not to prevent re-establishment late in the season.

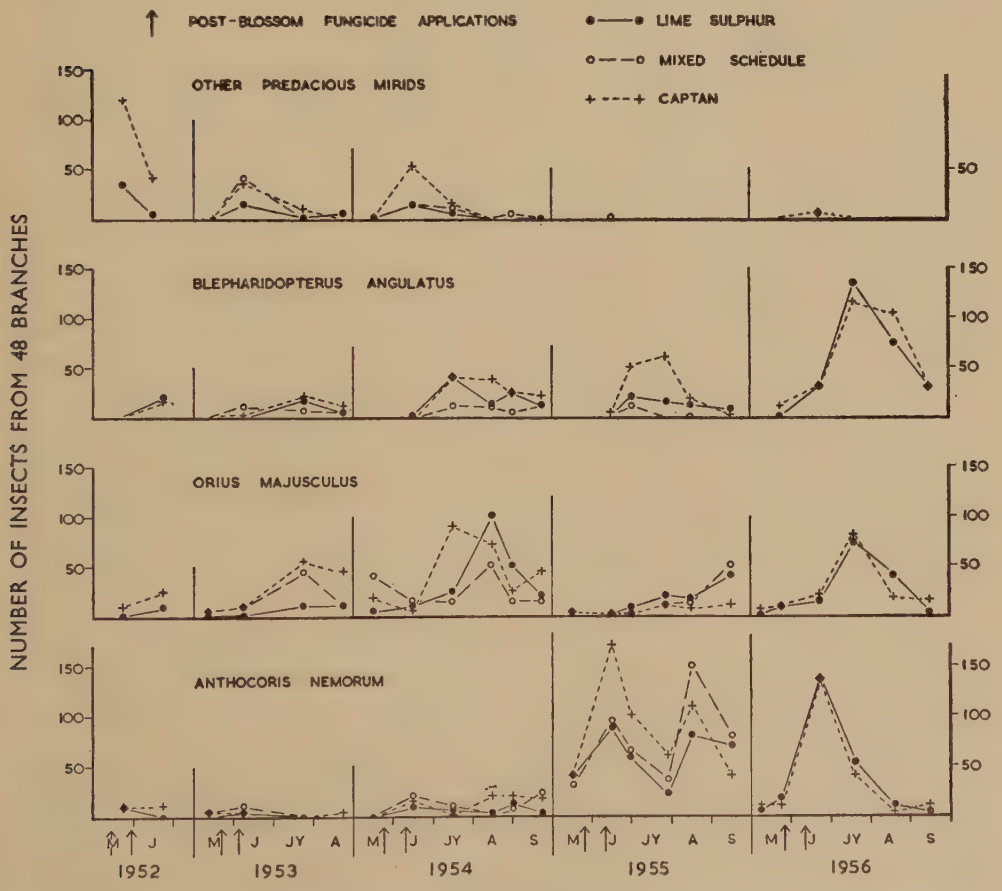

FIG. 3.

Population densities of predacious insects on the two principal treatments, 1952-56, and the mixed-schedule treatment, 1953-55, in the trial at Stondon Massey, Essex.

The use of DDT at bud-burst in 1953 and 1955 caused a great reduction in numbers of *Typhlodromus* early in both those years, but they recovered by mid-summer, though differences caused by the fungicide applications remained as great.

Fluctuations in densities of populations of predacious insects.

Many species of predacious insects were present from time to time and the data are therefore complex. Prey other than *M. ulmi* available in the orchard were *Bryobia praetiosa* (Koch), eriophyid mites (*Vasates schlechtendali* (Nal.)), aphids including the Woolly Aphid, caterpillars, Apple Sucker (*Psylla mali* Schm.), and typhlocybids. With all these organisms present, *M. ulmi* formed a less important ingredient in the diet of predatory insects than is usual in a commercial orchard, and it is not surprising that there was no close correlation between populations of this mite and of the predatory insects. However, total populations of insect predators, especially of the Black-kneed Capsid, *Blepharidopterus angulatus* (Fall.), increased from 1952 to 1956, being especially high on all plots in 1956, and this may have been related to the increase of *M. ulmi* which took place up to 1955.

The most abundant species were *Anthocoris nemorum* (L.), (also some *A. confusus* Reut. and *A. nemoralis* (F.)), *Orius majusculus* (Reut.), and *B. angulatus* ; records for these are given separately in Fig. 3. Other predacious mirids included *Campylomma verbasci* (M.-D.), *Psallus variabilis* (Fall.), *Atractotomus mali* (M.-D.), *Capsus meriopterus* (Scop.), and *Plagiognathus arbustorum* (F.) ; their numbers have been added together as they were not abundant after the first year and virtually absent in the last two. Lime sulphur in 1952 and 1954 reduced the populations of *C. verbasci* and *A. mali* ; these species were present as young nymphs when the post-blossom fungicide sprays were applied. The disappearance of this group of Hemiptera was probably due to the bud-burst applications of DDT in 1953 and 1955, and to a less extent to the repeated use of lime sulphur on two-thirds of the orchard. The increase in numbers of the Black-kneed Capsid thus gave rise to the condition found in most sprayed orchards, where this species is the sole surviving predacious mirid.

Populations of *A. nemorum* rose to a peak in June of each year and reached a second peak in August 1954 and 1955, but did not exceed an average of one per branch until 1955 and 1956. *O. majusculus* showed an alternation with the other anthocorids, being numerous in 1953 and 1954 and in July 1956, but relatively scarce in 1955. Differences in numbers of these species on the three treatments were again not marked.

The Black-kneed Capsid increased from year to year, reaching a maximum in 1956. This insect begins to hatch in June and has only one generation, with a population peak in July ; movement in August tends to even out populations by the end of that month. Differences between treatments were never great, but in 1953-55 the smallest numbers occurred on trees receiving the mixed schedule.

Analyses of the numbers of the three main predator species from 1954 to 1956 showed no significant differences, except for *A. nemorum* in 1955 when there was an indication ($P < 0{\cdot}05$), on two occasions (14th June and 27th July), of a higher population on captan trees. Generally speaking, there was no consistent difference in numbers of any of the three main insect predators, although there was an occasional indication that numbers of *Anthocoris* or *Orius* were lower where lime sulphur was used.

Occurrence of Bryobia *mites.*

Bryobia praetiosa (Koch) was found in the orchard in 1952 but disappeared from trees that received lime sulphur spray. On the captan plots, however, it increased in numbers up to 1955, when the density reached 2 per leaf, and at times it was much more abundant there than *M. ulmi.*

DISCUSSION.

This field experiment, continued for two years longer than the previous one (Collyer and Kirby, 1955), has shown that lime sulphur applied twice pre-blossom and twice post-blossom, plus DDT occasionally at bud-burst, can cause an increase of *M. ulmi* sufficient to give bronzing of the foliage in an orchard where this mite had not previously been important. Moreover, the use of lime sulphur pre-blossom, followed by captan post-blossom, similarly favoured the increase of *M. ulmi*, indicating that the effect of the lime sulphur was mainly due to the higher concentrations used in April and early May. When captan was used over the same period, even with the same applications of DDT, *M. ulmi* remained at a relatively steady low density.

The *M. ulmi* populations illustrated in Fig. 1 show a general rise over four years, followed by a sharp reduction in the fifth year. The peak in August 1955 on the captan trees was caused partly by dispersal from neighbouring plots, so that the marked rise and fall of *M. ulmi* is confined to the plots where lime sulphur was used ; this is typical of the interaction of this mite and its insect predators, particularly the Black-kneed Capsid (Collyer, 1953), the mite building up over a number of years with consequent increase of the predator, which finally becomes so abundant that mite populations are reduced suddenly as in 1956. The weather records over the five years suggest, however, that very serious mite infestations might have occurred, on lime sulphur plots at least, had the summer of 1956 been similar to that of 1955. During the whole period insect predators were as abundant on captan trees, where *M. ulmi* was scarce, emphasizing the probability that the mite was a minor source of food for them. The important issue is the development of the different *M. ulmi* densities on the two main treatments, a difference which was maintained ($P < 0{\cdot}05$) even in 1956, when mite numbers fell to low levels. There is no evidence of a difference in the numbers of any species of insect predator that can be correlated with the *M. ulmi* increase from 1953 to 1955. In 1956 insect predators were particularly abundant, and almost identical in numbers on both main treatments ; they could not have been responsible for the persisting differences in *M. ulmi* densities.

There was, however, a marked inverse correlation between *M. ulmi* and *Typhlodromus* populations throughout the experiment. Workers in Nova Scotia have found lime sulphur to cause " practical elimination " of *Typhlodromus* spp., whereas captan was without effect on *T. tiliae* (MacPhee and Sanford, 1956). The present authors know of no evidence from field trials that captan is toxic to *M. ulmi*, whereas lime sulphur has been regarded for years as a mild acaricide for this species. It seems unlikely, therefore, that the inverse correlation could be a direct result of the sprays.

It remains to be considered whether the differences in *T. tiliae* are sufficient to account for the divergence which developed in *M. ulmi* populations. *T. tiliae* may consume as many as three *M. ulmi* mites per day, but its needs are considerably less

(Collyer, 1956). However, it is active continuously from April until October. In insectary experiments, with a starting density of *M. ulmi* up to ten times that of *T. tiliae*, the predacious mite could obtain and maintain control over the phytophagous species, keeping it to a level not exceeding one mite per leaf (Collyer, 1958). On captan trees, in the trial reported here, *T. tiliae* was sufficiently abundant at all times to maintain control of *M. ulmi*. On lime sulphur trees, the ratio became somewhat unfavourable in 1953, and from this time *M. ulmi* populations gradually built up despite the insect predators. Once *M. ulmi* has become abundant, it is no longer possible for *Typhlodromus*, which always remains at low densities, to restrain its increase (Collyer, 1958). The eventual reduction of *M. ulmi* to a low level on lime sulphur plots in 1956 may have been the result of insect predator action. But the even lower level attained on captan trees must have been the result of another factor as well, which could have been *T. tiliae*, present in that year at about a quarter of the density of *M. ulmi*. *M. ulmi* population densities exceeding one per leaf occurred only where *T. tiliae* was absent, or present at a very low density, except where dispersal may have temporarily overrun the predator in August 1955.

M. ulmi populations increased sharply from August to September on lime sulphur trees in 1953, 1954 and 1955, and on mixed-schedule trees in 1954 and 1955, while those on captan trees did not (Fig. 2). As a result, large winter egg populations on lime sulphur trees were followed by large mite populations in the spring, far above the capacity of the *Typhlodromus* populations. The Black-kneed Capsid, on the other hand, disappeared in August, so that only on captan plots, where a favourable ratio of *M. ulmi* to *Typhlodromus* existed in August, could *M. ulmi* control be expected.

Although the most reasonable explanation for the difference in *M. ulmi* populations appears to be the action of *Typhlodromus*, the presence of other, as yet unrecognized, factors is not ruled out. Ecological studies of the various components of this complex are needed, in the absence of the complications involved when chemicals are used. Nevertheless, the results would imply a need for changes in the spray programme if the potential aid of beneficial species in the control of *M. ulmi* is to be harnessed. Fungicides adequate for control of scab and/or mildew seem likely to be essential for a long time yet, but those used should, unlike lime sulphur, be harmless to beneficial insects and mites. The full value of such a modification would only be realized if other spray chemicals in the programme were likewise harmless.

SUMMARY.

Fungicide schedules based on lime sulphur or captan have been applied to large plots of Cox's Orange Pippin trees for five consecutive seasons ; a mixed schedule, of lime sulphur pre-blossom and captan post-blossom, was also used in the middle three years. Insecticides were restricted during this period to nicotine and lead arsenate, and to bud-burst applications of DDT in the second and fourth years.

In the first year, numbers of *Metatetranychus ulmi* (Koch) remained below one per leaf. In all subsequent years, numbers on plots receiving lime sulphur, even pre-blossom only, exceeded this level, causing bronzing in 1955. On plots which received captan only, numbers remained substantially lower, seldom exceeding one per leaf.

The predacious mite, *Typhlodromus tiliae* Oudms., was always more plentiful on captan-only trees. In the third and fourth years numbers on the mixed-schedule were if anything lower than on lime sulphur-only plots. These densities showed a marked

inverse correlation with those of *M. ulmi* ; on lime sulphur plots (but never on captan plots), the ratio frequently exceeded ten *M. ulmi* to one *T. tiliae*, i.e. exceeded the controlling capacity of the predacious mite.

One or more species of predacious insects were abundant in all seasons. Of these, *Anthocoris* spp. and *Orius majusculus* (Reut.) alternated seasonally and within seasons. The Black-kneed Capsid, *Blepharidopterus angulatus* (Fall.), increased each year ; densities were similar on lime sulphur and on captan plots, except in the fourth year, but tended to be lower on plots where the mixed schedule was used. Other predacious mirids, abundant at the start of the experiment, became negligible by the fourth year, being adversely affected by lime sulphur and DDT. Neither the numbers of total insect predators nor of individual species showed any consistent correlation with *M. ulmi* numbers for any treatment, although such a correlation could have been obscured in this trial by the presence of a number of prey species besides *M. ulmi*.

The inverse correlation between *M. ulmi* and *Typhlodromus* numbers has been consistent in this and a previous trial by the present authors, lending support to the idea, although not providing proof, that *Typhlodromus* mites are an important factor in the biological control of *M. ulmi* in south-east England. Whereas the use of captan as a fungicide allowed natural control of *M. ulmi* at an economic level, the use of lime sulphur resulted in the gradual development of *M. ulmi* populations sufficient to cause bronzing of the foliage in the fourth year.

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RESISTANCE TRIALS OF SOME APPLE ROOTSTOCK VARIETIES TO *PHYTOPHTHORA CACTORUM* (L. & C.) SCHROET.

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TRUNK infection of apple by *P. cactorum* was first described by Baines (1935, 1938, 1939) following a severe epidemic in Indiana orchards. Baines' work provided a necessary stimulus for more detailed investigations of collar injury and subsequently the disease was diagnosed in Canada (Welch, 1942), New Zealand (Smith, 1950; Northcote, 1954), England (Smith, 1953; Sewell, 1957), Germany (Braun, 1952; Braun and Kröber, 1953), Holland (ten Houten, 1953 ; Buddenhagen, 1955) and Belgium (Soenen and Busschots, 1954).

It now seems probable that the difficulty of isolating the causal organism had resulted in many previous cases of *Phytophthora* crown, collar and trunk injury being attributed to other causes, e.g. fireblight and physiological disorders such as winter damage, waterlogging, " sour sap " or " The Death" (Baines, 1935, 1939 ; Welch, 1942 ; Smith, 1950). Nevertheless, while *P. cactorum* may be the most important cause of collar and root injury in certain apple varieties, it would be wrong to assume that all such damage is due to this particular pathogen. It is possible, for example, that *Phytophthora syringae* Klebahn may be responsible for some root and collar rots. This fungus, although never isolated from naturally occurring rots, has been shown to be virulent to apple by Buddenhagen (1955) ; similar virulence, together with a fairly widespread soil distribution has also been demonstrated by the present authors (unpublished). Furthermore, the harmful effects of waterlogging and low temperatures, in the absence of any known pathogen, have recently been restated by Cooley (1948) and Cooley and Groves (1950).

Marked differences in the resistances of rootstock and scion varieties have been noted. In European countries and New Zealand the variety recorded as being most severely attacked by *P. cactorum* is Cox's Orange Pippin (ten Houten, 1953 ; Smith, 1950, 1953 ; Northcote, 1954 ; Soenen and Busschots, 1954 ; Buddenhagen, 1955 ; Sewell, 1957). Severe disease outbreaks have largely been confined to orchards where Cox tissues are below, or in close proximity to, the soil. In reviewing the results of an extensive survey in New Zealand, Woodhead (1957) has shown that infection of Cox was reduced by at least 75 per cent. when this variety was top-worked (i.e. worked several feet above the ground on established trees cut back for regrafting), and that in topworked trees up to 40 years of age *Phytophthora* infection was insignificant. He therefore suggests that orchards of Cox's Orange Pippin should be planted with trees worked in such a way that no Cox tissues are close to the ground. The later topworking of Cox upon other varieties, or high working on planted root-stocks run up to provide resistant stems, is recommended. Although Woodhead

advocates 30 inches as a safe height for working this variety, observations in English orchards suggest that Cox tissues more than 12 inches above soil level would be almost completely free from the disease.

Clearly the usefulness of high-working susceptible, or normal-working resistant, scion varieties will be determined by the resistance of the rootstock. The present investigations were undertaken, therefore, to determine the relative resistances of a wide range of East Malling rootstocks to as many isolates of *P. cactorum* from apple as was practicable. The rootstocks tested include the more important varieties of the Malling series, all Malling-Merton rootstocks (Preston, 1955) except MM.114, and the six M.IX Crosses (3426, 3428, 3430, 3431, 3436 and 3438) selected by Tydeman (1943) and Preston (1954). The variety 3436 of the latter group is now designated M.26 (Rogers, 1958).

Materials and methods.

Experiment 1 (Table I).

Unworked 1- and 2-year-old rootstocks were grown in John Innes potting compost in 5-inch clay pots, sunk in gravel beds in the open.

Four trees each of 29 rootstock varieties were inoculated with the following five isolates of *P. cactorum:*

Culture No.	*Source.*
P1	Cox lesion, Worcestershire.
P3	Cox lesion, East Malling Research Station, Kent.
P7	Apple lesion, Cologne, Germany (No. Ag. 1621).
P9	Cox lesion, Kent.
P10	Cox lesion, Essex (Cheshunt 589).

Date of inoculation : 12-14.6.56.

Date lesions recorded : 12-14.9.56.

The stems were inoculated in June approximately 10 cm. above soil level by removing with a cork-borer a disc of bark 4 mm. in diameter so as to expose the cambium. The bark disc was then replaced by a cornmeal agar disc of the same size taken from a 3-week-old plate culture of *P. cactorum.* The inoculation wound was covered with Vaseline-coated muslin and firmly bound with adhesive polythene tape.

Results of these inoculations were recorded after 3 months by removing the external, corky bark and measuring the vertical length of the lesion ; stem girth was recorded at the same time.

No lesion developed in any of the control plants which were inoculated with sterile cornmeal agar discs.

Experiment 2 (Table I).

After the completion of Experiment 1 all apparently unaffected stem tissues were cut into 6-inch lengths. These stem pieces, inoculated as described above, were stood in 1 in. of water in glass jars and incubated at 20° C. for 21 days before lesions were recorded. The rootstock varieties, *Phytophthora* isolates, and replication, were the same as in Experiment 1 except for the omission of the following inoculations :

TABLE I.

Mean lesion lengths (mm.) on twenty-nine apple rootstock varieties after inoculation with P. cactorum.

Rootstock	Isolates of *P. cactorum*									
	Experiment 1					Experiment 2				
	P1	P3	P7	P9	P10	P1	P3	P7	P9	P10
M.I	15	10	8	0	14	5	16	15	7	8
M.II	9	3	20	5	2	5	6	0	5	13
M.VII	0	0	0	0	0	0	0	3	0	0
M.IX	0	0	14	2	0	0	1	**55**	0	0
M.XII	**118**	26	**93**	9	**150**	**36**	**29**	**33**	8	**61**
M.XIII	**89**	**61**	50	3	39	**24**	**28**	**22**	1	**34**
M.XVI	39	**109**	37	8	**95**	**20**	**33**	**20**	3	**38**
M.XXV	0	0	36	2	21	3	5	**20**	0	0
MM.101	0	8	28	0	12	0	0	15	0	0
MM.102	33	3	46	0	16	6	0	15	0	0
MM.103	**141**	**117**	**88**	3	**87**	**28**	**35**	**31**	0	**34**
MM.104	0	**105**	2	4	8	9	16	8	0	15
MM.105	0	2	23	0	12	0	0	6	0	6
MM.106	0	0	0	0	0	2	2	12	5	5
MM.107	51	**58**	44	0	**84**	12	17	13	—	16
MM.108	0	0	15	0	0	4	2	13	0	0
MM.109	15	13	22	0	24	8	20	10	0	7
MM.110	**93**	50	36	0	46	**19**	17	**17**	7	28
MM.111	0	0	0	2	0	6	0	14	0	6
MM.112	19	29	52	0	42	0	0	**28**	0	7
MM.113	**243**	**87**	**160**	10	**231**	**79**	—	**45**	—	**31**
MM.115	53	**52**	**81**	0	**79**	3	0	**18**	0	0
3426	0	0	2	0	0	8	0	**30**	0	0
3428	7	0	25	0	7	0	0	**23**	0	0
3430	0	0	11	0	0	1	0	**16**	0	0
3431	0	0	14	0	3	0	2	**23**	0	0
3436 (M.26)	**70**	40	45	2	47	7	0	**36**	0	0
3438	**58**	37	40	5	44	9	15	**21**	0	3
Crab C	22	18	18	5	26	**19**	**39**	15	0	23
Cox	—	—	—	—	—	**87**	**95**	**78**	9	**86**

NOTE. Figures in bold print are significantly greater than the corresponding figure for M.II ($P = 0{\cdot}05$). In these two experiments none was significantly less than M.II.

MM.113 with P3 and P9, and MM.107 with P9. Cut lengths of 2-year-old branches of Cox's Orange Pippin also were included in this test. The method of storing cut stem lengths and the lesions resulting from this method of testing are illustrated in Figs. 1 and 2.

Date of inoculation: 17.9.56.

Date lesions recorded : 8.10.56.

Experiment 3 (Table II).

The methods used were the same as in Experiment 1. Five trees each of 20 rootstock varieties were inoculated with the following three isolates of *P. cactorum*:

Culture No.	*Source.*
P23	Bramley lesion, Kent.
P25	Cox lesion, Sussex.
P29	Cox lesion, Kent.

Date of inoculation : 24-25.6.57.

Date lesions recorded : 20-22.8.57.

Results.

In presenting these results (Tables I and II) M.II has been selected as a standard for estimating the relative resistances of rootstocks. This variety has consistently shown high resistance in the field under various soil conditions as well as in extensive inoculation tests. Furthermore, there is general agreement on the high resistance of M.II among several investigators from different countries (see Table IV).

Table II.

Experiment 3. Mean lesion lengths (mm.) on twenty apple rootstock varieties after inoculation with P. cactorum.

Rootstock	Isolate of *P. cactorum*		
	P23	P25	P29
M.I	**18**	**26**	**20**
M.II	8	10	7
M.VII	1	8	1*
M.IX	2	0*	1*
M.XII	14	**23**	9
M.XIII	11	12	**17**
M.XVI	**20**	16	**14**
M.XXV	3	2*	0*
MM.101	7	9	4
MM.102	3	7	2
MM.103	10	12	12
MM.104	7	5	8
MM.105	1	3	4
MM.106	0*	2*	0*
MM.109	4	8	0*
MM.110	13	11	11
MM.113	**23**	**23**	**18**
MM.115	5	3	3
Crab C	**18**	15	9
Northern Spy	6	2*	0*

Note. Figures in bold print are significantly greater than the corresponding figure for M.II; those marked with an asterisk are significantly less ($P = 0{\cdot}05$).

All results were subjected to analyses of variance and in Tables I and II mean lesion lengths significantly greater ($P = 0{\cdot}05$) than the corresponding figure for M.II are presented in bold print.

The results of the three experiments are summarized in Table III, where the rootstocks are arbitrarily divided into three resistance classes. The order in which the rootstocks are presented is that of their *average* reaction to the several isolates tested, and differences between adjacent rootstocks, or groups of rootstocks, are

TABLE III.

Rootstock varieties arranged in order of average resistance to several isolates of P. cactorum.

Resistance	Rootstock varieties
High	M.VII; MM.106; Northern Spy; 3430; MM.111; MM.108; 3426; MM.105; 3431; M.IX; MM.101; 3428; M.XXV; MM.104*; M.II; MM.109; MM. 102; MM.104
Intermediate ..	M.I; Crab C; MM.112
Low	MM.115; 3438; 3436 (M.26); MM.110; M.XIII; MM.107; M.XVI; MM.103; M.XII; MM.113

* MM.104 is included here ignoring the P3 inoculation result in Experiment 1 (see text).

not necessarily statistically significant. In this Table MM.104 is shown in two positions since the overall mean for this variety was greatly increased by low resistance to one isolate alone (P3 in Experiment 1) but this was not subsequently confirmed (Experiment 2). Its "higher resistance" classification, therefore, is based on the overall mean, omitting this single result. All rootstock varieties except MM.113 showed considerably greater resistance than Cox's Orange Pippin in Experiment 2.

"High Resistance" Rootstock Varieties. MM.101, MM.102, MM.105, MM.108, MM.111, MM.106, MM.109, M.VII, M.IX, M.XXV and Northern Spy all exhibited high resistance comparable to that of M.II, and the last six varieties even occasionally showed a significantly *greater* resistance than M.II. M.VII and MM.106 showed exceptionally high resistance in all tests. MM.104 was highly resistant in all tests except one, as has already been noted. M.IX, M.XXV, 3426, 3430, 3431 and 3438 were somewhat similar in their behaviour to MM.104 in showing lower resistance than M.II each on one occasion only : it is interesting to note that these six varieties, including M.IX and four of its progeny (viz., 3426, 3430, 3431, 3438), all showed low resistance to the same isolate (P7) under the conditions of the cut-stem test (Experiment 2).

"Intermediate Resistance" Rootstock Varieties. Although Crab C did not differ significantly from M.II in Experiment 1, the low resistance shown in the subsequent cut-stem test was confirmed in the 1957 tree inoculations. M.I behaved differently in the 1956 and 1957 series of inoculations, and MM.112 varied considerably in resistance to different isolates and also under differing test conditions. In view of the variable behaviour of these three varieties, therefore, they are regarded as forming a group of intermediate resistance.

"Low Resistance" Rootstock Varieties. MM.103, MM.113, M.XII and M.XVI exhibited very low resistances in nearly all tests and M.XIII, MM.107, MM.110, MM.115, 3436 (M.26) and 3438 showed low resistances generally differing from M.II either at the 5 or at the 10 per cent. level of significance.

DISCUSSION

The results of the present studies are closely comparable with those obtained by other investigators using similar clonal rootstock varieties (see Table IV). Thus,

Table IV.

Summary of rootstock resistances recorded by other investigators.

Author	Locality	Resistance		
		High	Intermediate	Low
Fitzpatrick *et al* (1944) ..	B.C., Canada	M.II M.IX	M.XVI	M.I Merton 789
Palmer (1949)	B.C., Canada	M.II M.VII M.IX	M.XII M.XVI	M.I
Smith (1950)	New Zealand			Merton 789
Tukey (1952)	U.S.A.			M.I.
McIntosh and Mellor (1953) ..	B.C., Canada	M.VII M.IX		
Smith (1955)	New Zealand	Northern Spy Merton 779 Merton 793 M.II MIX	M.XV M.XVI	M.XIII M.XV MXVI Merton 789
		Malling-Merton vars. in order 106, 114, 108, 111, 104, 112		MM.102 MM.109 MM.113

M.II, M.VII, M.IX and Northern Spy have consistently been found highly resistant and M.XII, M.XIII and M.XVI are regarded as being of intermediate or low resistance. There is, of course, little published information at present concerning the resistances of the recently issued Malling-Merton rootstocks. Smith (1955), however, has tested nine of these varieties by a technique somewhat similar to that used in Experiment 2, employing inoculation of short root lengths in the laboratory. His results conform with those presented above in demonstrating that MM.113 showed very low resistance, MM.112 was intermediate, and MM.106, MM.108, MM.111 and MM.104 were all highly resistant. The divergence in Smith's results for MM.102 and MM.109 may be due to differences in the fungal isolates, host tissues or test methods.

The five rootstocks (MM.104, MM.106, MM.109, MM.111 and M.XXV) which were recently distributed for multiplication in Britain (Preston, 1953) are of considerable promise in showing resistances frequently greater than those of the Malling series of rootstocks which they may eventually replace.

These inoculation studies demonstrated that marked variation exists both in varietal resistance of the host and in pathogenicity of different isolates of *P. cactorum*. Also some varieties, normally highly resistant, were severely attacked by particular isolates under certain test conditions, e.g. M.IX and the M.IX Crosses in Experiment 2 and MM.104 in Experiment 1. The cultural lines of *P. cactorum*, P9, used in these tests were virtually non-pathogenic, even to Cox's Orange Pippin, although this isolate was obtained from a severely infected Cox orchard. Other cultural lines of

P9, however, have proved to be highly pathogenic, thus indicating that the virulence of certain lines may have diminished in culture. Apart from this possible loss of pathogenicity by P9, differences were also noted between the pathogenicities of different isolates. Thus, for example in Experiment 1, isolate P3 was significantly less pathogenic than were P1, P7 and P10 ($P = 0{\cdot}05$) over the range of varieties tested. Similar pathogenic variation is noted by Baines (1938) and Smith (1955). It is possible, therefore, either that strains of this omnivorous and variable parasite capable of attacking the more resistant varieties may be encountered, or that the normal resistance of rootstocks may break down under certain field conditions (cf. McIntosh and Mellor, 1953).

Stem inoculations essentially provide a measure of the inherent resistance of the rootstocks and do not necessarily reflect their *liability* to infection in the field (which may perhaps be influenced by other factors such as the occurrence of wounding), nor the extent to which the fine root systems of these varieties may be attacked. The effects of soil-infestation with *P. cactorum* on the overall growth of a wide range of rootstocks, as distinct from the more obvious and startling attack on crown and collar, are being investigated.

SUMMARY.

A number of rootstocks of the Malling, Malling-Merton and M.IX Crosses series were each inoculated with several isolates of *P. cactorum*, the causal organism of Collar Rot and Crown Rot. All rootstock varieties were susceptible to attack by this soil-borne pathogen, but all showed greater resistance than Cox's Orange Pippin. There were marked differences in the rootstock resistances and the pathogenicities of different isolates. M.XII, M.XIII, M.XVI, M.26 (3436), MM.103, MM.107, MM.110, MM.115, MM.113 and 3438 were considered to be of relatively low resistance and M.I, Crab C and MM.112 of intermediate resistance. All other rootstocks were of high resistance comparable to that of M.II ; these include the five rootstocks (MM.104, MM.106, MM.109, MM.111 and M.XXV) which have recently been released to propagators in Britain.

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PLATE I.

Fig. 1.
Method of storing cut stem and branch lengths after inoculation with *P. cactorum*.

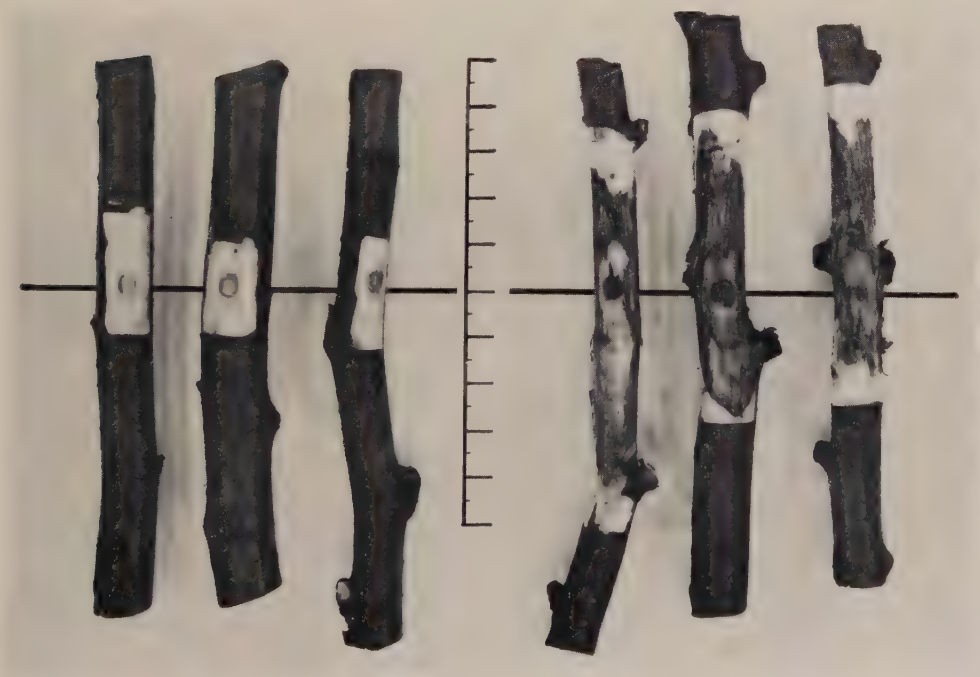

Fig. 2.
External corky bark removed to show lesions on cut branches of Cox's Orange Pippin 21 days after inoculation with *P. cactorum*. The three branches on the left were inoculated with sterile cornmeal agar discs.

[*face p. 58*

BOOK REVIEWS

THE U.C. SYSTEM FOR PRODUCING HEALTHY CONTAINER-GROWN PLANTS. Edited by KENNETH F. BAKER (University of California Division of of Agricultural Sciences, Agricultural Experiment Station). Manual 23. 1957. Pp. 332, illus. Price $1·00.

This book, edited by the Professor of Plant Pathology at the University of California College of Agriculture with contributions from nine of his colleagues in the Department or in the Agricultural Extension Service, is written primarily for the Californian nursery industry.

The U.C. system is based on the philosophy that, for economic plant production, disease must be eliminated by growing clean stock in clean soil and containers, using hygienic cultural practices. Disorders due to poor nutrition, salinity or toxicity must be avoided and mechanization must be used to reduce labour costs.

An important feature is the use of five basic soil mixes to which various fertilizer mixes may be added. The number of possible combinations of sand, peat and fertilizer is, at first sight, bewildering, but a series of tables restricts the choice for certain plants to half a dozen mixes or fewer.

The English reader will compare the U.C. soil mixes with the more familiar John Innes composts. The most obvious differences are the omission of turf loam from the U.C. soil mixes and the use of fine instead of the coarse sand required in the J.I. composts.

While the U.C. soil mixes are stated to give excellent results in Californian conditions, a strict comparison with J.I. composts on the basis of plant growth for several species commonly grown in this country would be most interesting.

The salinity problem, which is probably more serious in California than in U.K., is discussed and some of the examples given of salinity damage, e.g. tip burn on *Maranta leuconeura*, will be familiar to readers in this country and the partial sterilization of soil by both steam and chemical methods is treated in considerable detail. Steam is favoured for general use.

Much use is made of the English research work on steam sterilization. Other aspects not so familiar in this country are various mechanized methods of soil heating, in which the soil flows continuously through the sterilizing equipment, and which are particularly intended for soil to be used in containers. In general these methods are stated to be less satisfactory than steaming the soil and the containers together after the latter have been filled. It is surprising to find the recommendation that the soil should be held at 212° F. for as long as 30 minutes but this is justified because the toxicity problem does not arise and the additional cost of thus ensuring against defects in the steaming process is relatively small.

Other sections of the book deal with soil-borne diseases, nutrition, the maintenance of healthy stock, growers' experience with the U.C. system and mechanization in the nursery. There is an appendix listing many papers referred to in the text. A good index and bold sub-headings in the text make reference a simple matter and the illustrations and diagrams are good.

It contains much information of interest to horticulturists in general and is an extremely good dollar's worth.

L.G.M.

HORTICULTURAL EXPERIMENT STATION AND PRODUCTS LABORATORY —THE FIRST FIFTY YEARS, 1906–1956. Ontario Department of Agriculture. Pp. 76, illus.

This modestly written and produced publication, issued by the Ontario Department of Agriculture, marks the 50th anniversary of the Vineland Station, the name of which has become familiar to horticultural research workers all over the world. The objective of the Station's effort down through the years has been service to the grower and to the horticultural industry, whether directly or indirectly. The 76 pages of this volume give ample evidence of how well the purpose of the Station has been fulfilled.

To many, Vineland will first be associated with the breeding of fruits and vegetables and, in particular, with the famous " V " peaches which, if they are now giving way to improvements in the Niagara peninsula, are still, we are told, the backbone of the Okanagan peach industry. But the Station has introduced many varieties of fruits and vegetables, some of which have proved useful beyond the confines of North America. Canadians will value particularly the Station's service in providing nurseries and fruit growers with true-to-name propagating material, but the results of the work on nutrition of fruits and vegetables, though primarily concerned with the soils and climate of the Niagara peninsula, have their application well beyond that comparatively restricted area. In recent years the establishment of the Horticultural Products Laboratory and the Grape Sub-station have made possible a considerable extension of the Station's usefulness.

The 50th anniversary coincides with the retirement of Mr. E. F. Palmer, for forty years Director, and the appointment of Dr. W. H. Upshall, who already has twenty-five years of research at Vineland to his credit, as his successor. Thus, in a sense, this must mark the end of one period and the start of a new one. Nevertheless, we are assured that a Station with such a proud record can only continue to develop and will go from strength to strength.

T.N.H.

PUBLICATIONS RECEIVED

HORTICULTURAL ADVANCE, Vol. I, December 1957. (Published by The Horticultural Research Institute, Saharanpur, India. Price Inland, Rs. 12·00. Abroad, Rs. 15·00.)

SCIENTIFIC HORTICULTURE, Vol. XIII, April 1958. The Journal of the Horticultural Education Association (H.E.A. Publication, c/o Gibbs & Sons, Orange Street, Canterbury, Kent. Price 17s. 6d.)

THE ENCYCLOPAEDIA OF GARDEN PESTS AND DISEASES. By J. Van Konynenburg and W. N. Lawfield. (London : W. H. & L. Collingridge Ltd. ; New York : Transatlantic Arts Inc. 1958. Pp. 215, illus. Price 42s.)

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1. All **manuscripts** should be in double-spaced typewriting, with a good margin, and should be addressed to the Editor, East Malling Research Station, near Maidstone, Kent, England. Papers must be written concisely. Historical reviews should be as short as possible and only such references to literature as bear directly on the subject should be included. Tables and illustrations, if any, must be only such as are absolutely essential for clear presentation.

2. Authors of papers containing extensive **numerical observations** should consult the recommendations of the British Association Committee on Biological Measurements, 1927, obtainable from Burlington House, London, W.1, price 6d. Arrangements have been made whereby original data too extensive for complete publication may be deposited at the British Museum (Natural History), London, S.W.7, or with the Royal Society of Edinburgh, 22 George Street, and thus be available for consultation by other workers. Full bibliographical reference to the publication in which the results are summarized must be supplied with the data.

3. Each paper must conclude with a concise and critically correct **summary** of its actual content. It should contain any new or verified constants as well as any other critical data of permanent value but not tables or graphs. Any organism mentioned should be given its scientific name.

4. Where a paper is of a highly technical nature it should be preceded by a brief **synopsis**, in which its contents are simply and clearly stated for the benefit of non-technical readers.

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6. The **scientific names** given in the "List of Common British Plant Diseases", published by the British Mycological Society (Cambridge University Press, 1944, revised edition in the press) and "Common Names of British Insect and other Pests" (Min. Agr., Fish. and Food, Tech. Bull. 6. H.M.S.O. 7/6 net) must be employed.

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10. The suggested **abbreviation** for the title of this publication is *J. hort. Sci.*

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